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Chang et al.

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(54) **RADIOGRAPHIC IMAGING ARRAY
FABRICATION PROCESS FOR METAL
OXIDE THIN-FILM TRANSISTORS WITH
REDUCED MASK COUNT**

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H01L 27/146 (2006.01)

(52) **U.S. Cl.**
CPC **H01L 27/14658** (2013.01); **H01L 27/14676**
(2013.01); **H01L 27/14687** (2013.01); **H01L**
27/14692 (2013.01)

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USPC 250/370.08; 438/59; 257/E31.085
See application file for complete search history.

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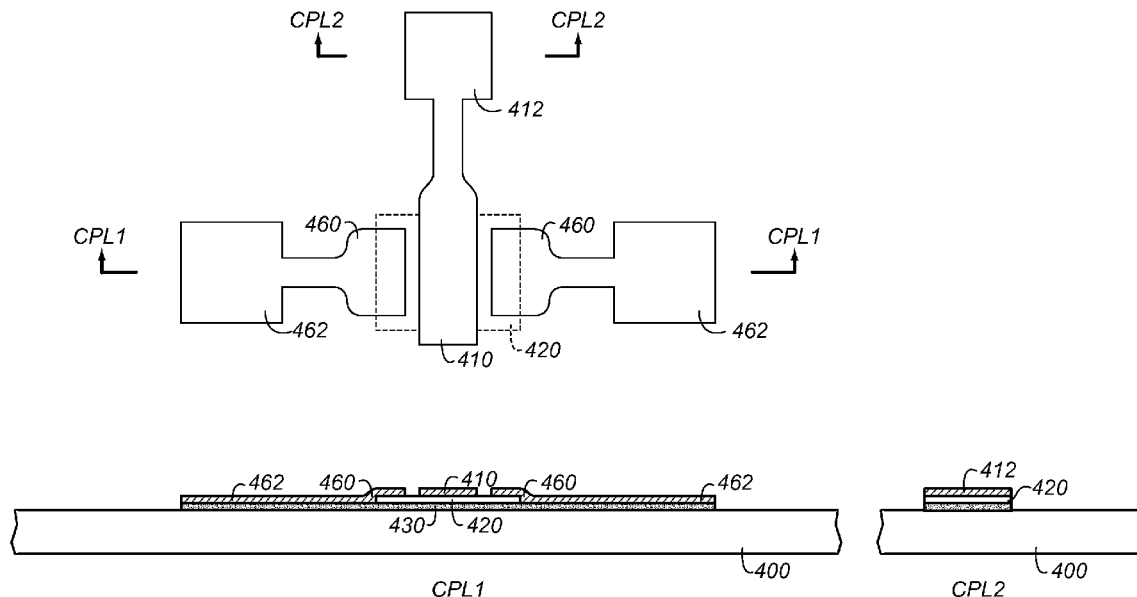
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(57) **ABSTRACT**

Embodiments of radiographic imaging systems; radiography
detectors and methods for using the same; and/or fabrication
methods therefore can include radiographic imaging array
that can include a plurality of pixels that each include a
photoelectric conversion element coupled to a thin-film
switching element. In certain exemplary embodiments, thin-
film switching element is a metal oxide (e.g., a-IGZO) TFT
manufactured using a reduce photolithography mask counts.
In certain exemplary embodiments, the thin-film switching
element is a metal oxide (e.g., a-IGZO) TFT that includes
reduced lower alignment tolerances between TFT electrodes.
In certain exemplary embodiments, the thin-film switching
element is a metal oxide (e.g., a-IGZO) TFT including a
reduced thickness active layer.

19 Claims, 23 Drawing Sheets



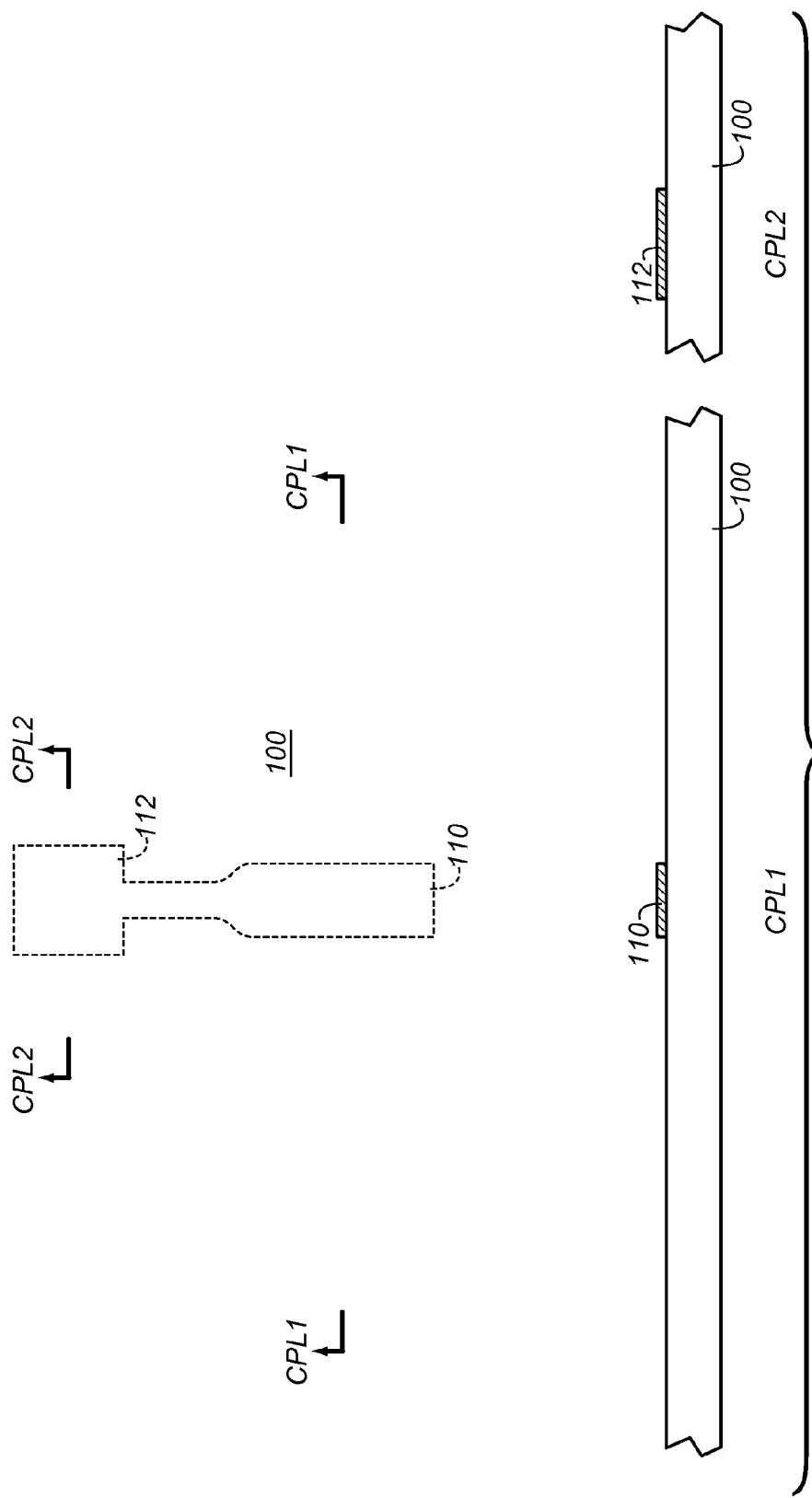
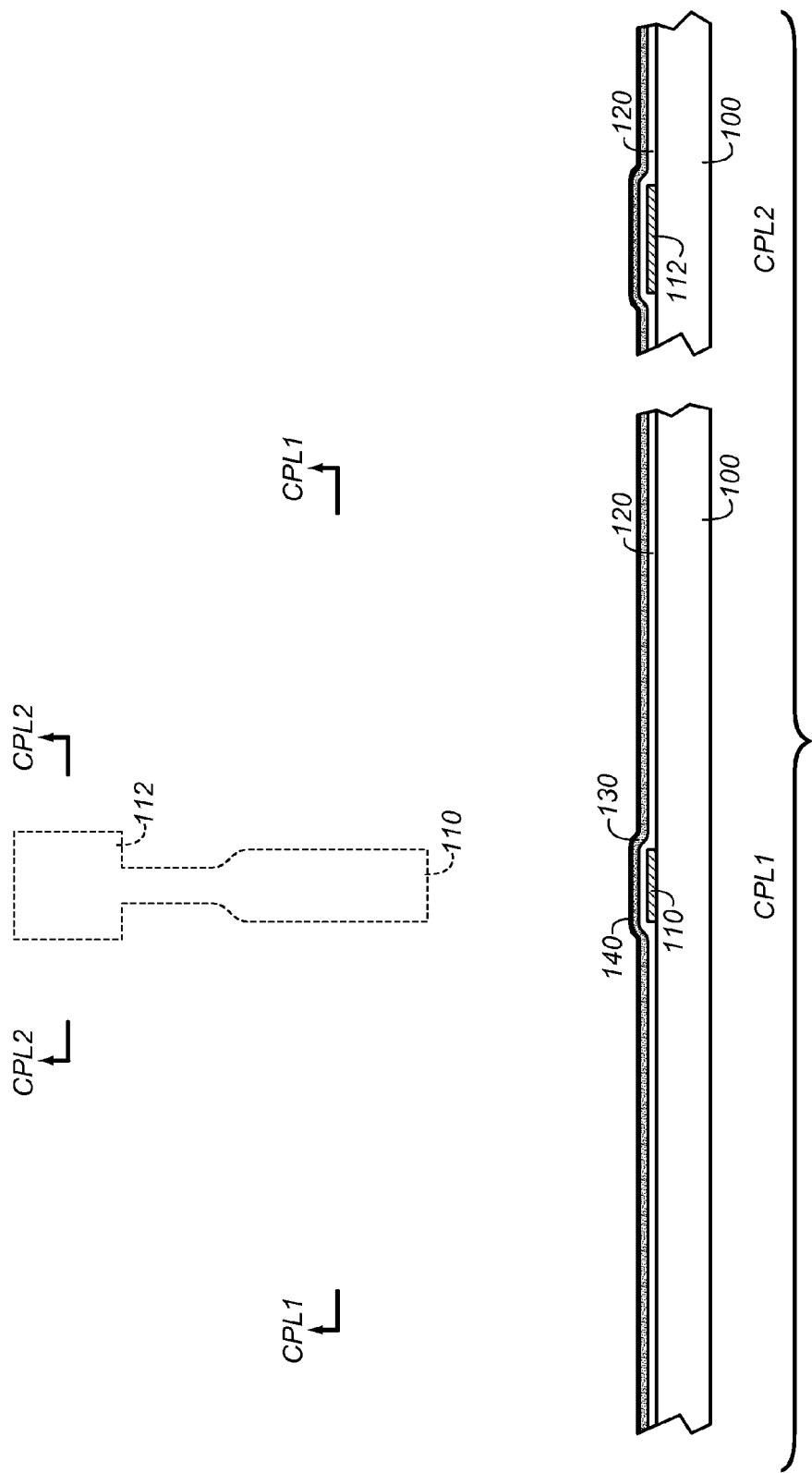
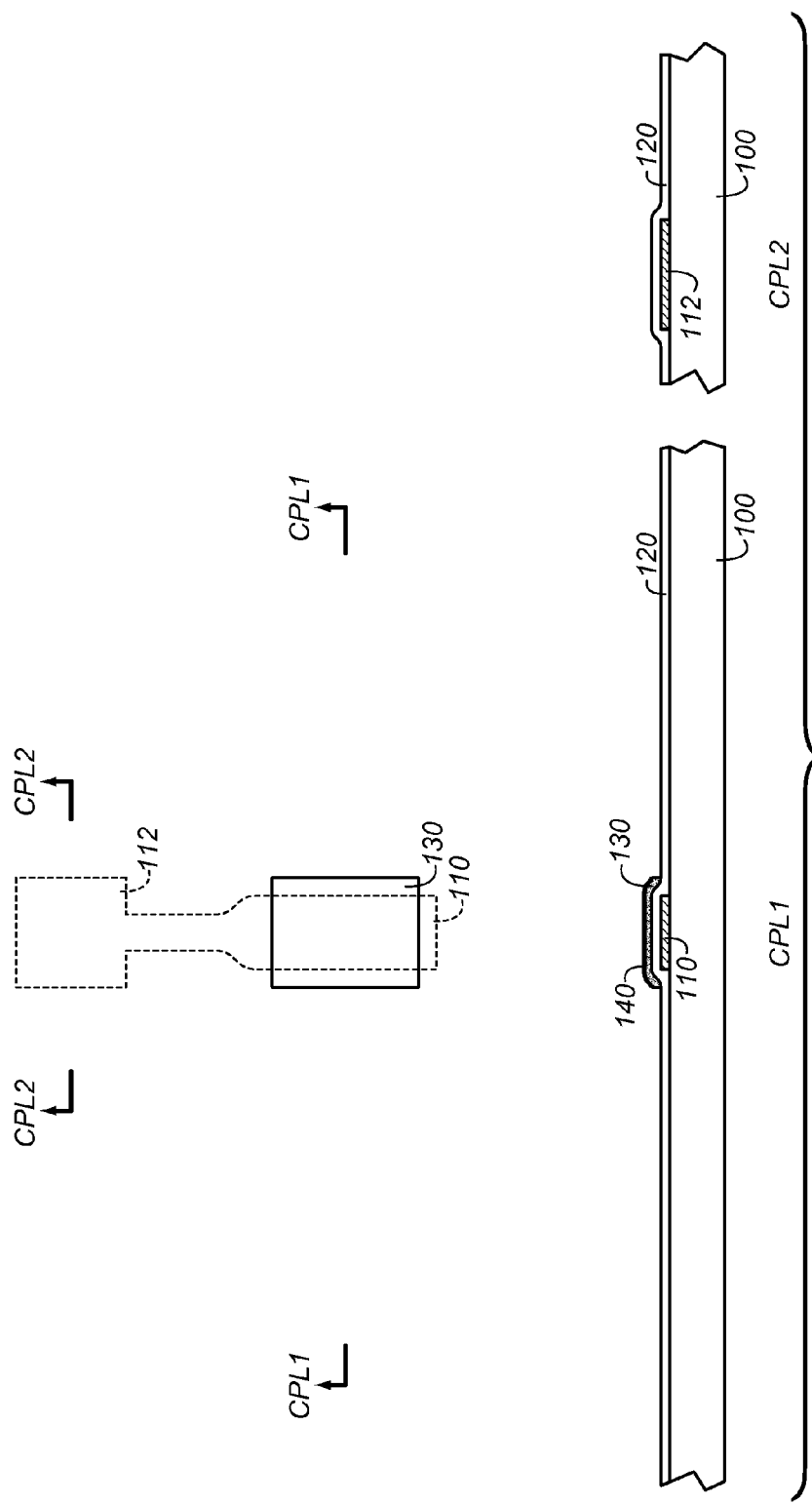


FIG. 1A
(PRIOR ART)





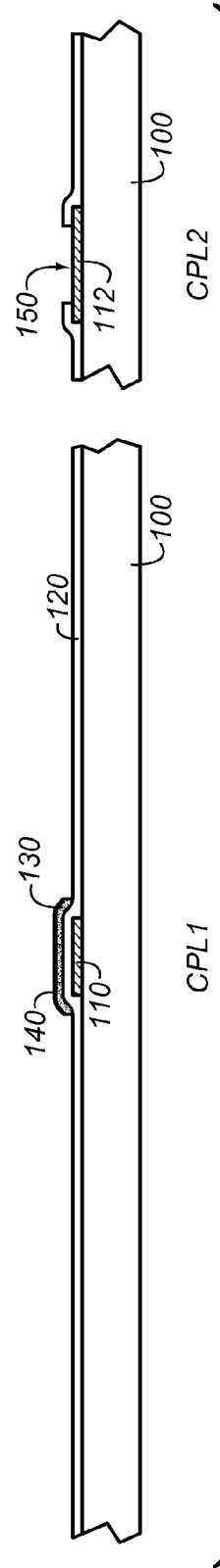
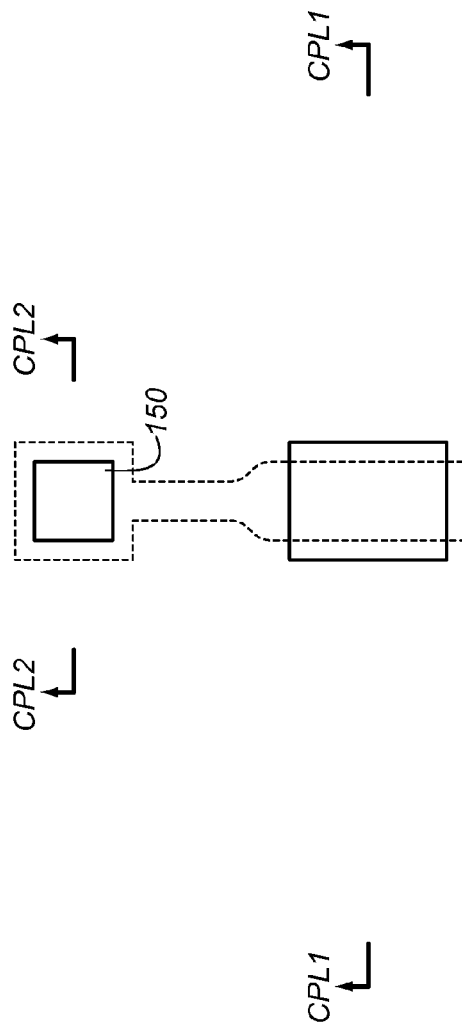
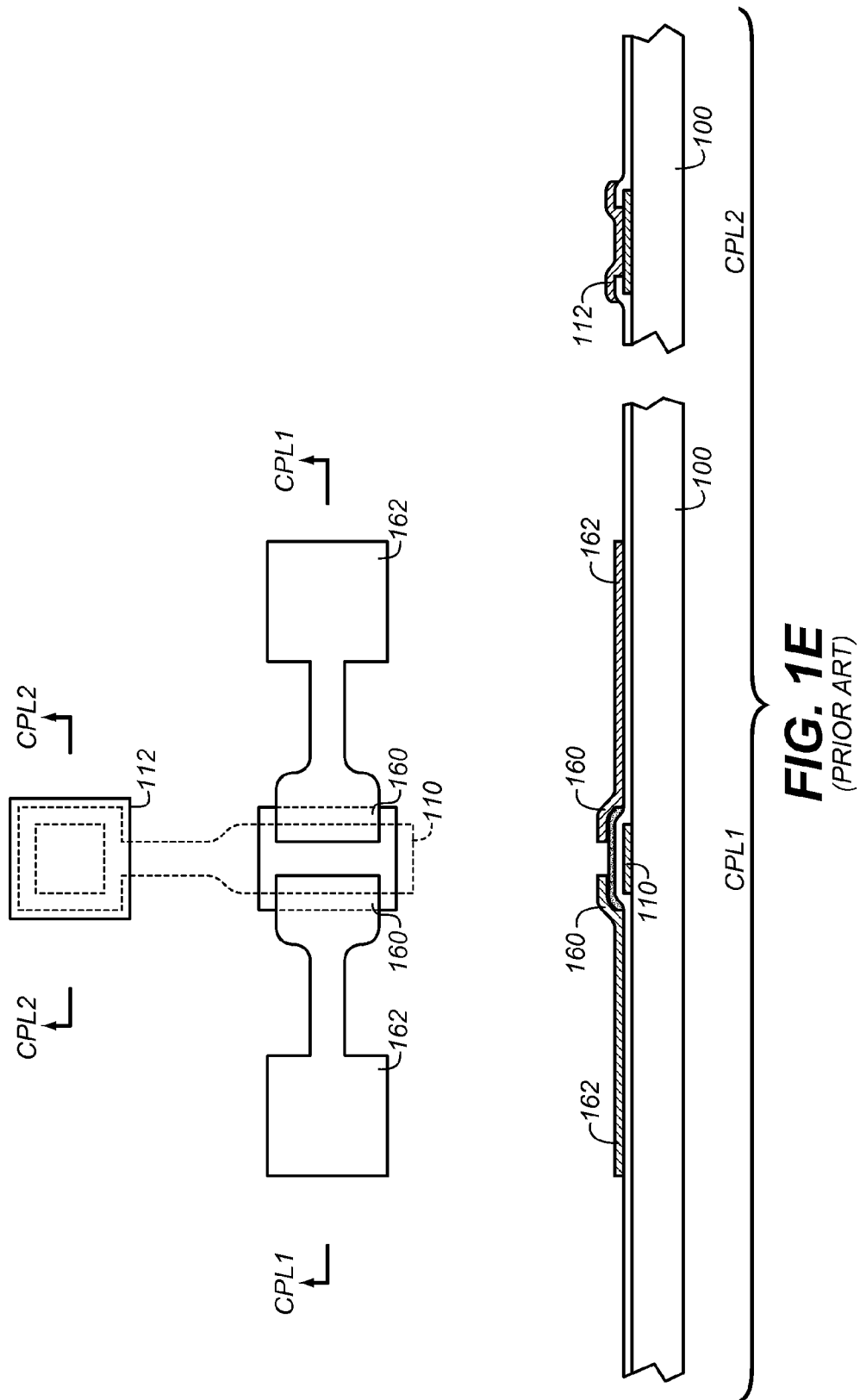


FIG. 1D
(PRIOR ART)



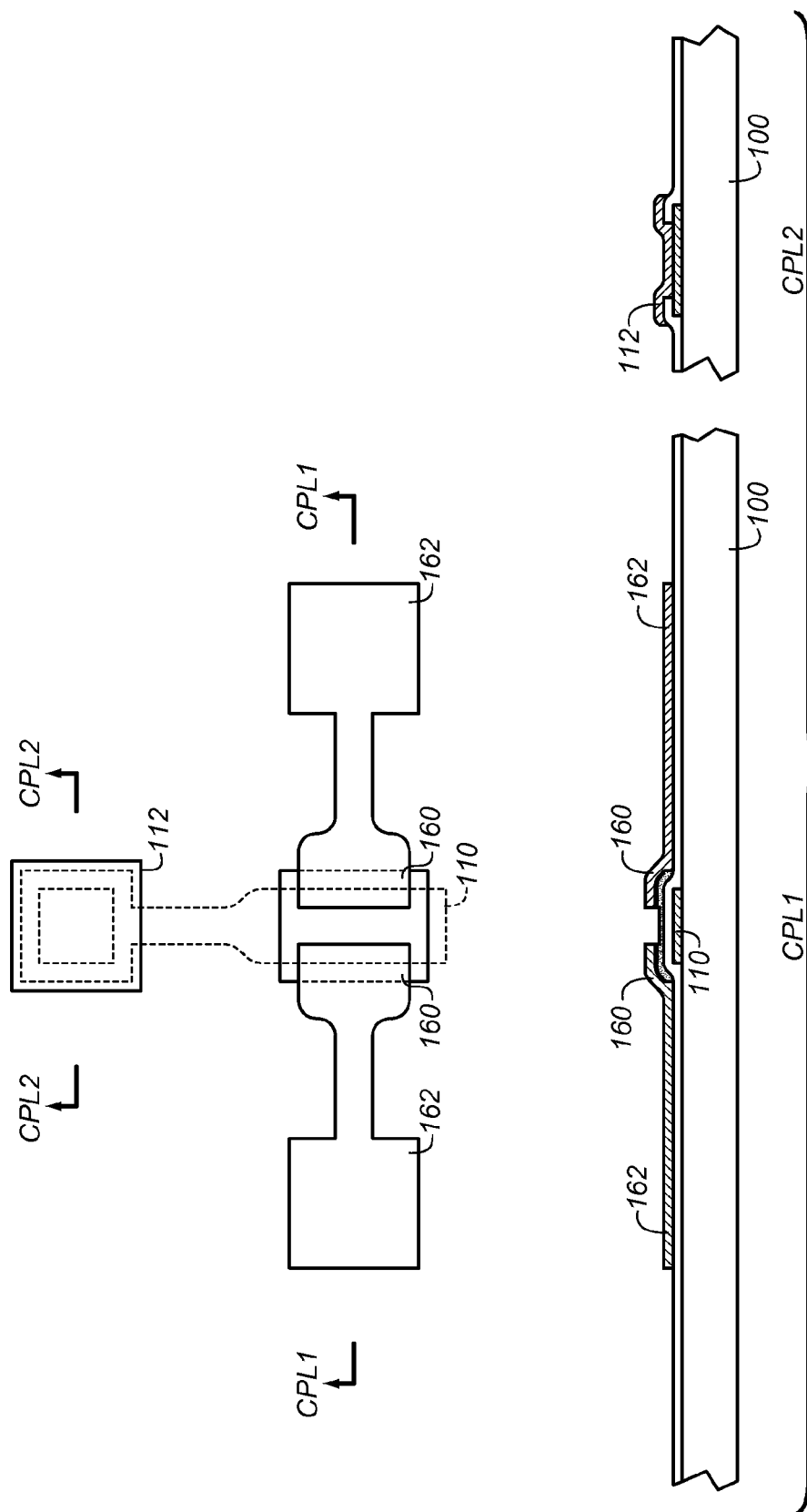


FIG. 1F
(PRIOR ART)

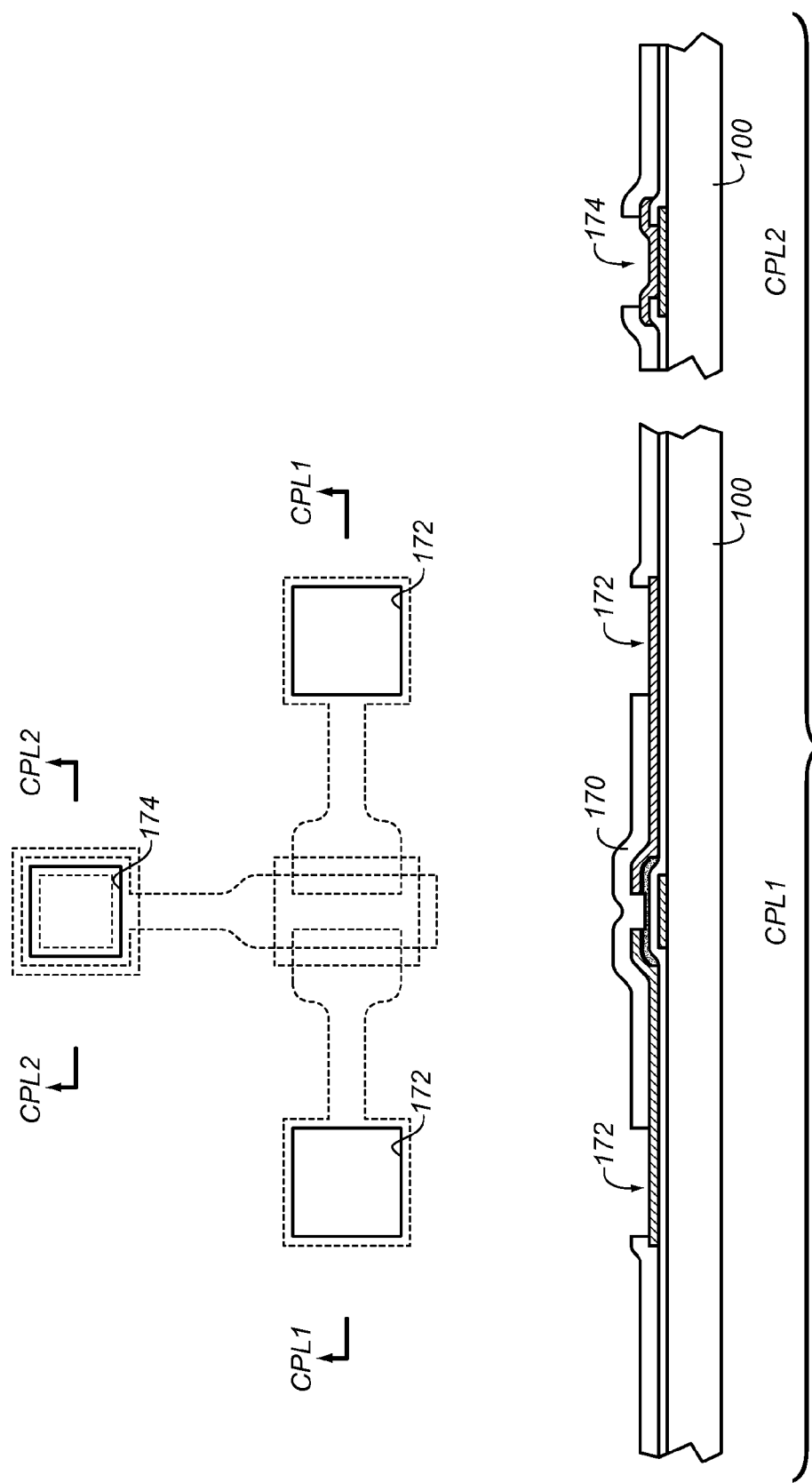
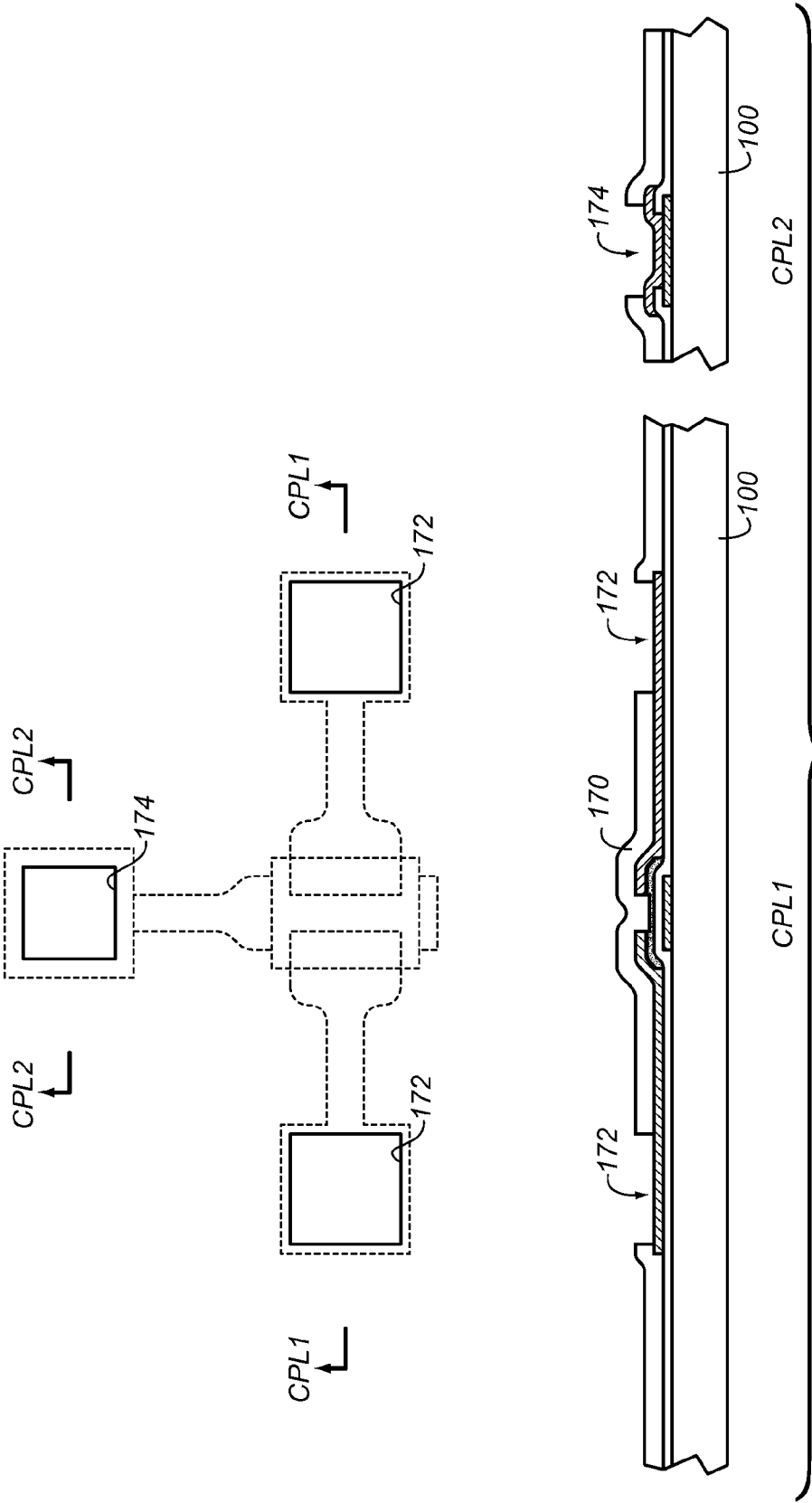


FIG. 1G
(PRIOR ART)



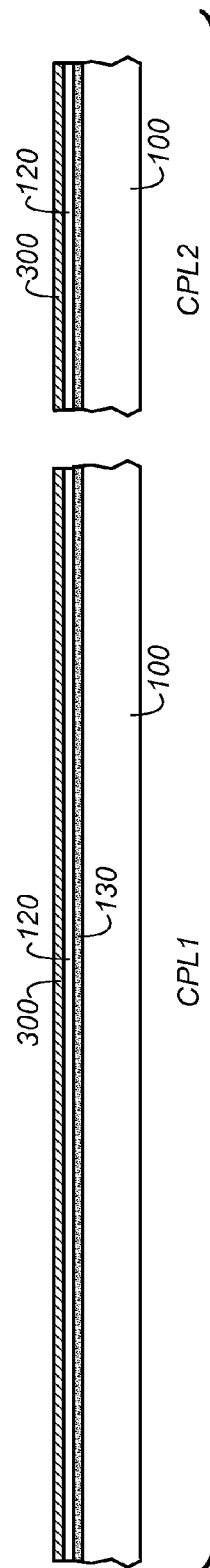
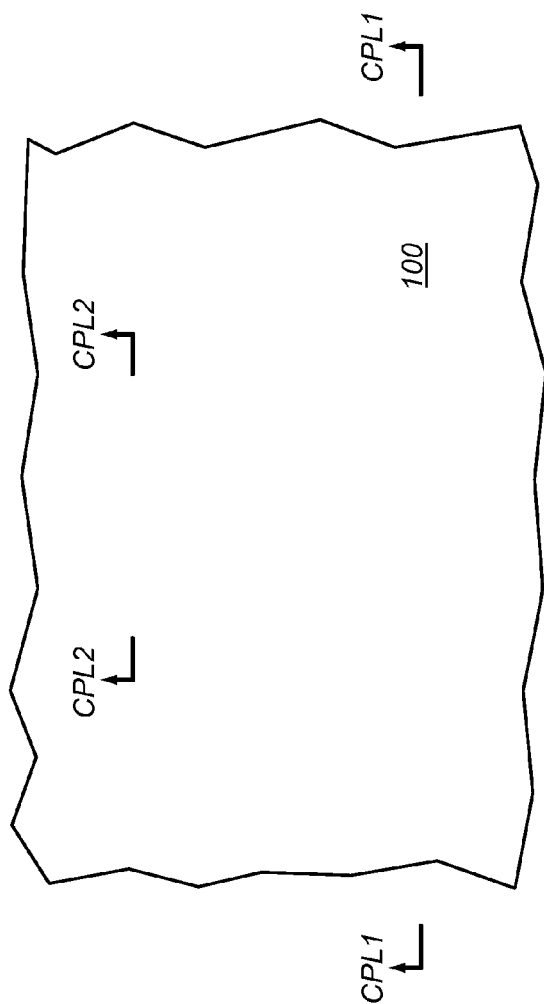
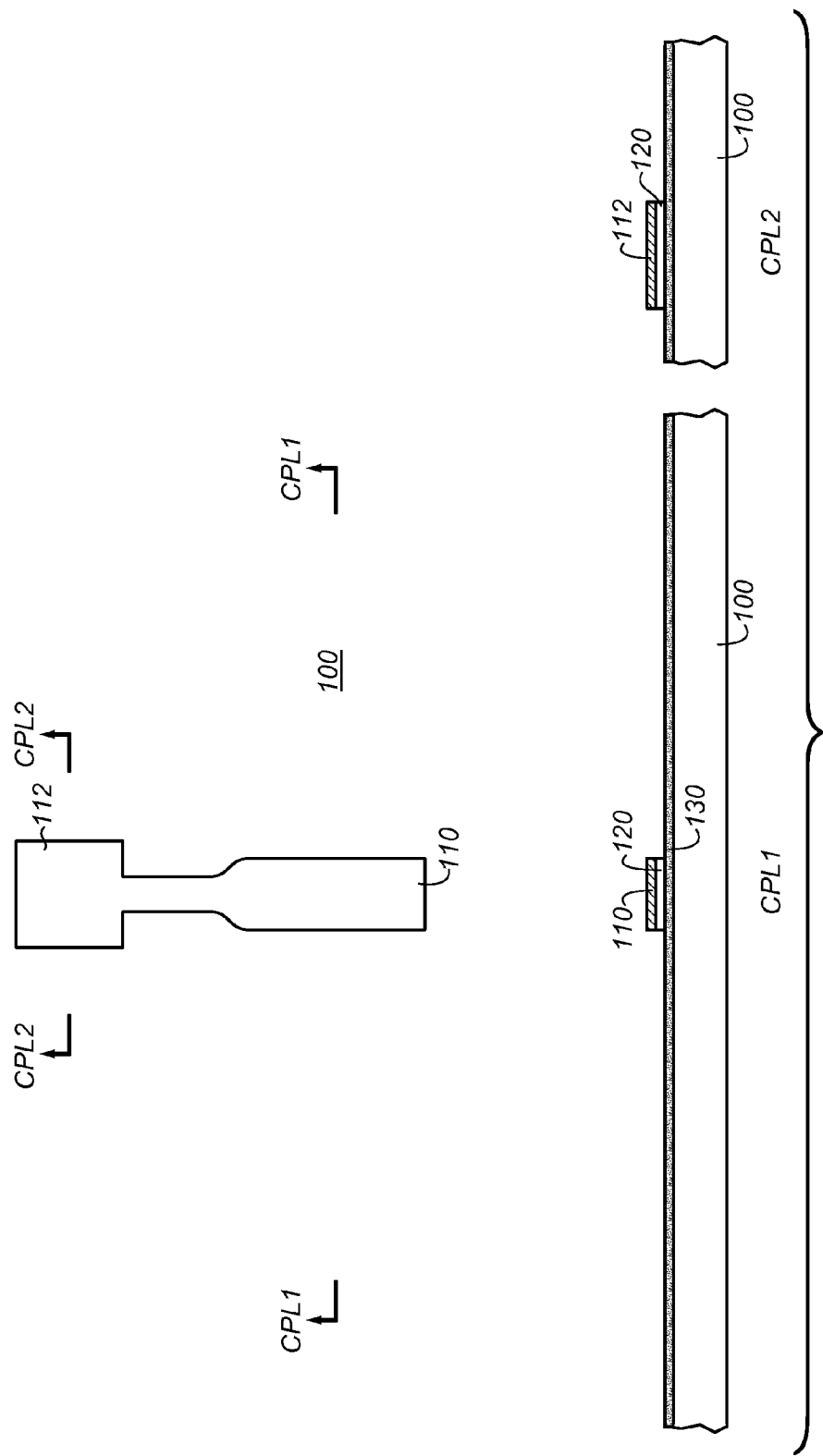
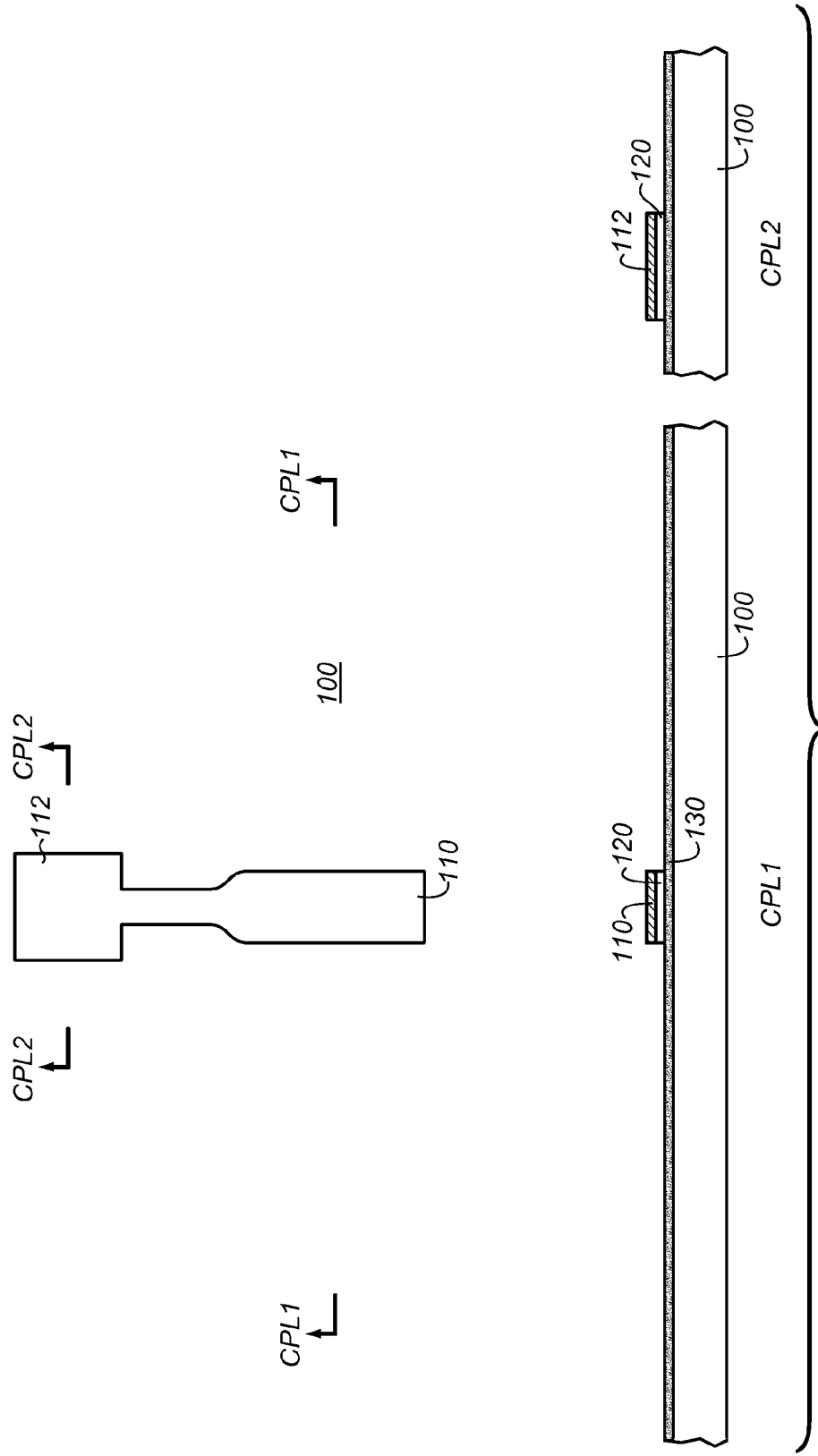


FIG. 3A
(PRIOR ART)





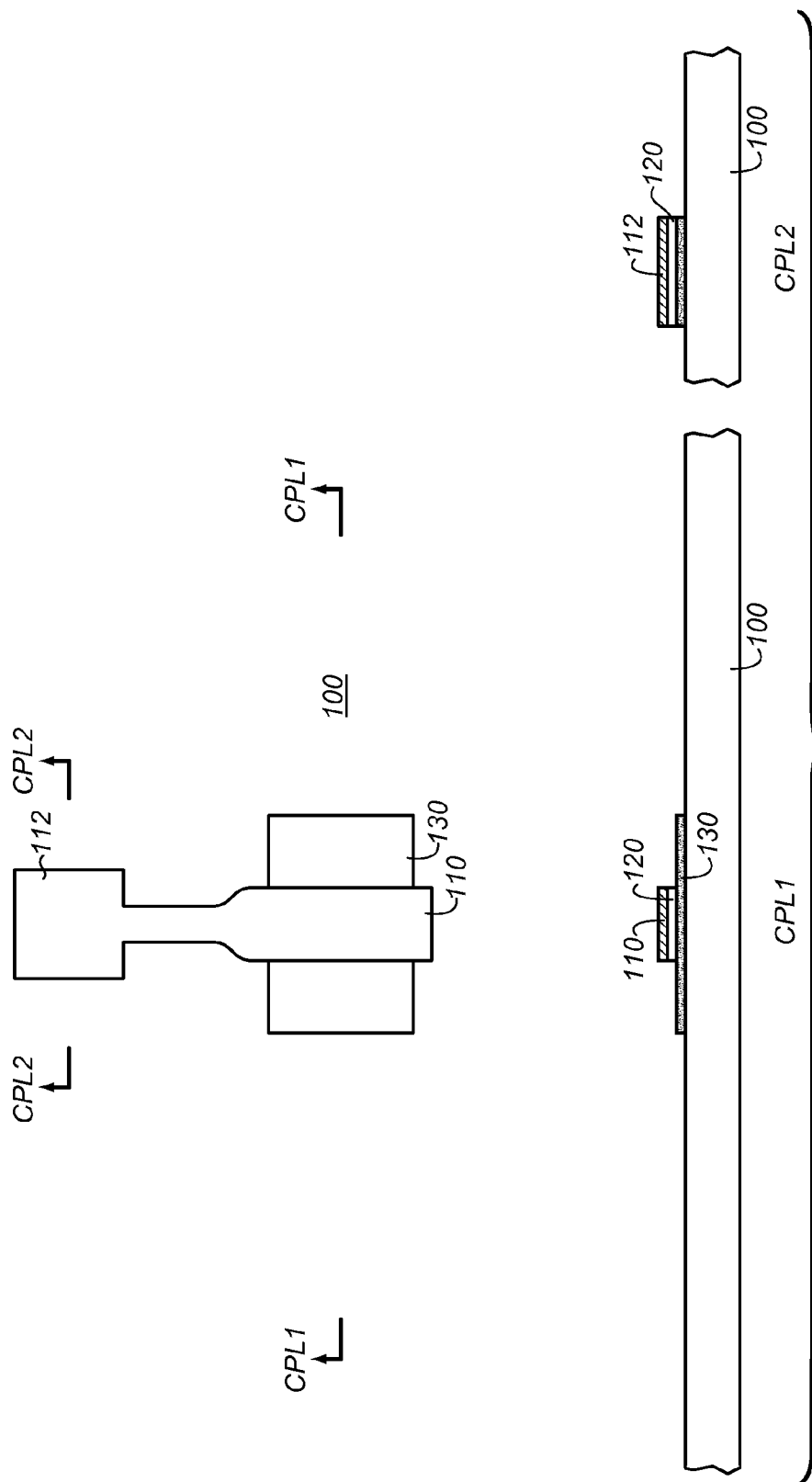
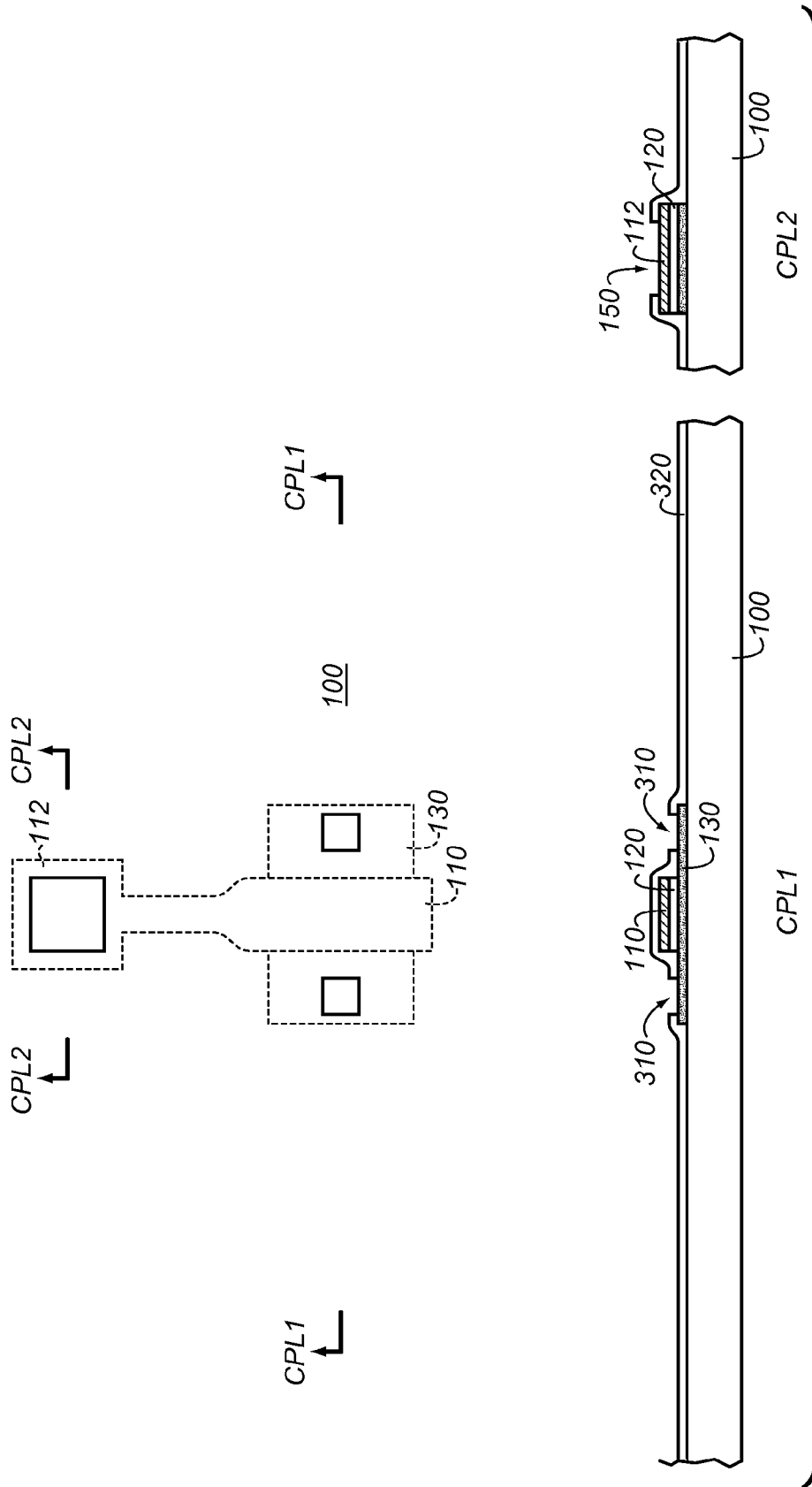
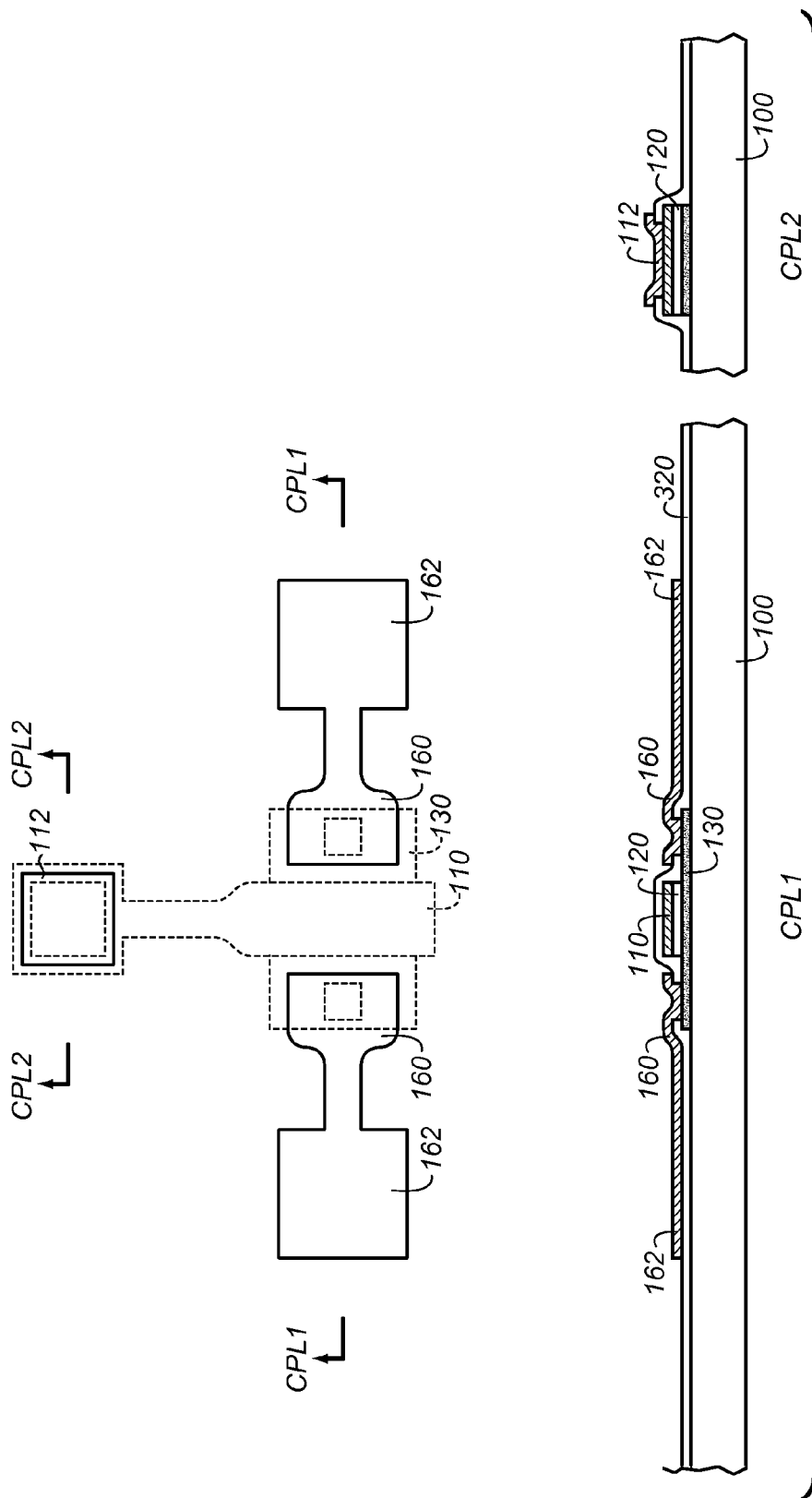
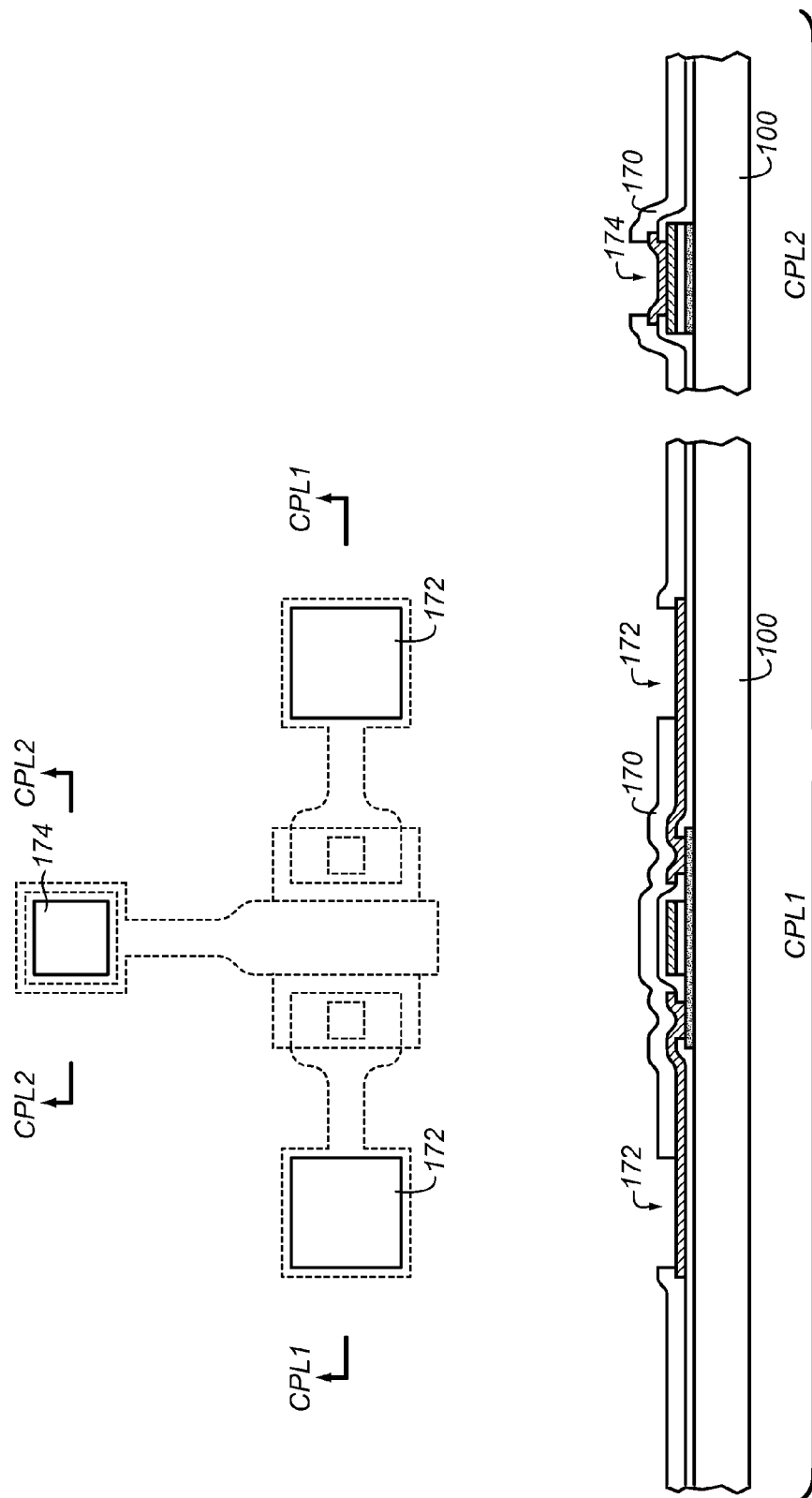
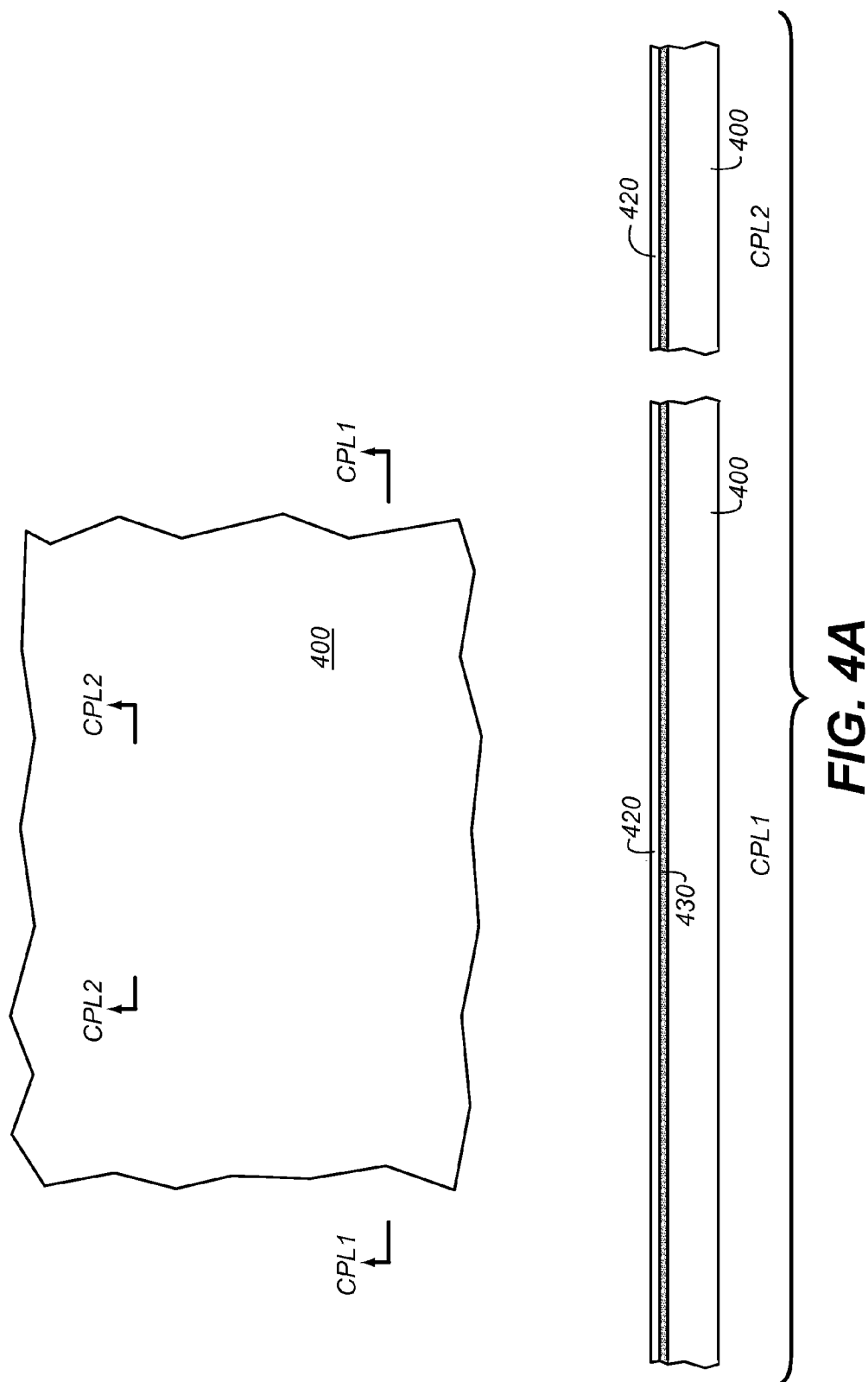


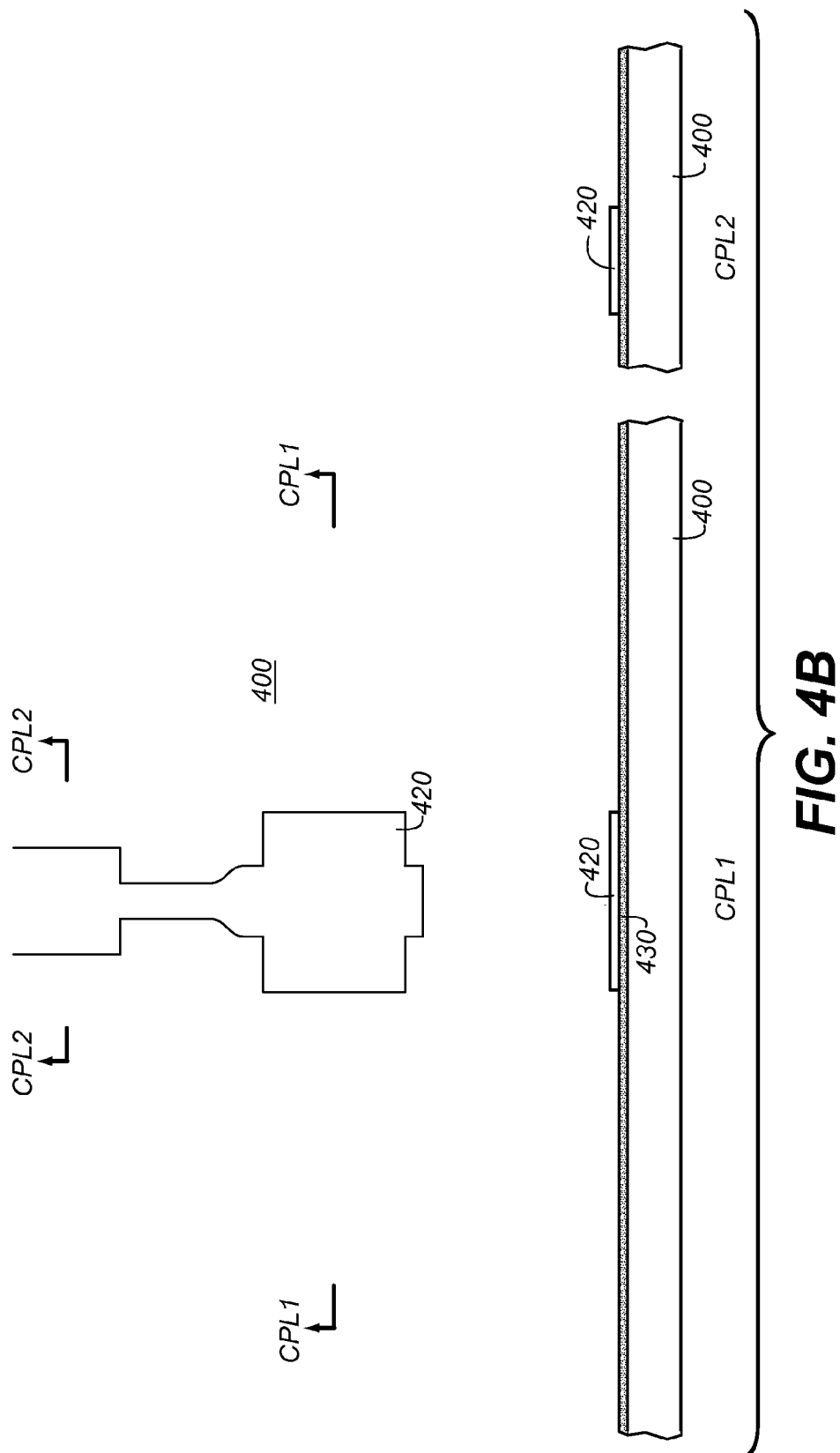
FIG. 3D
(PRIOR ART)

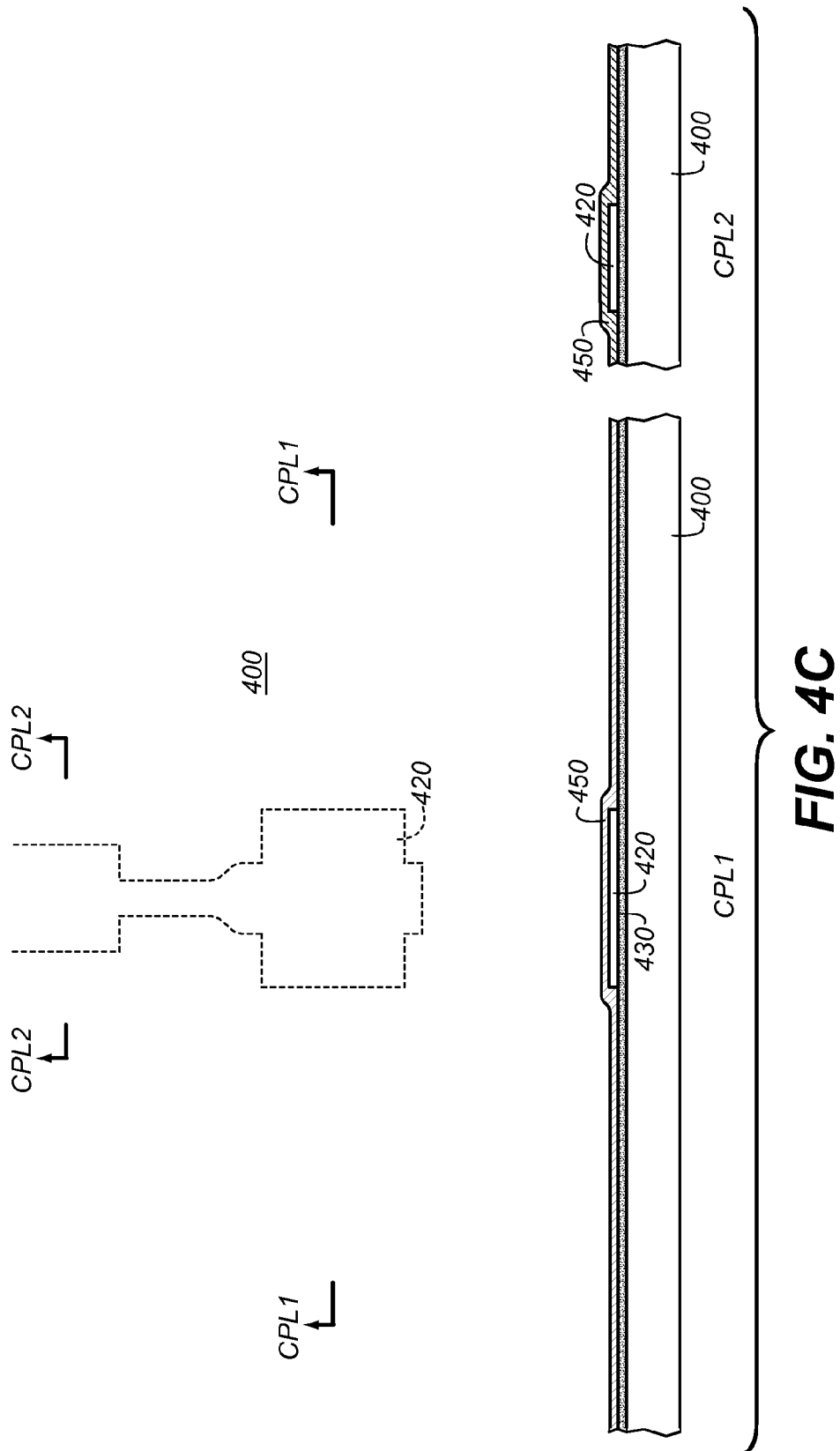












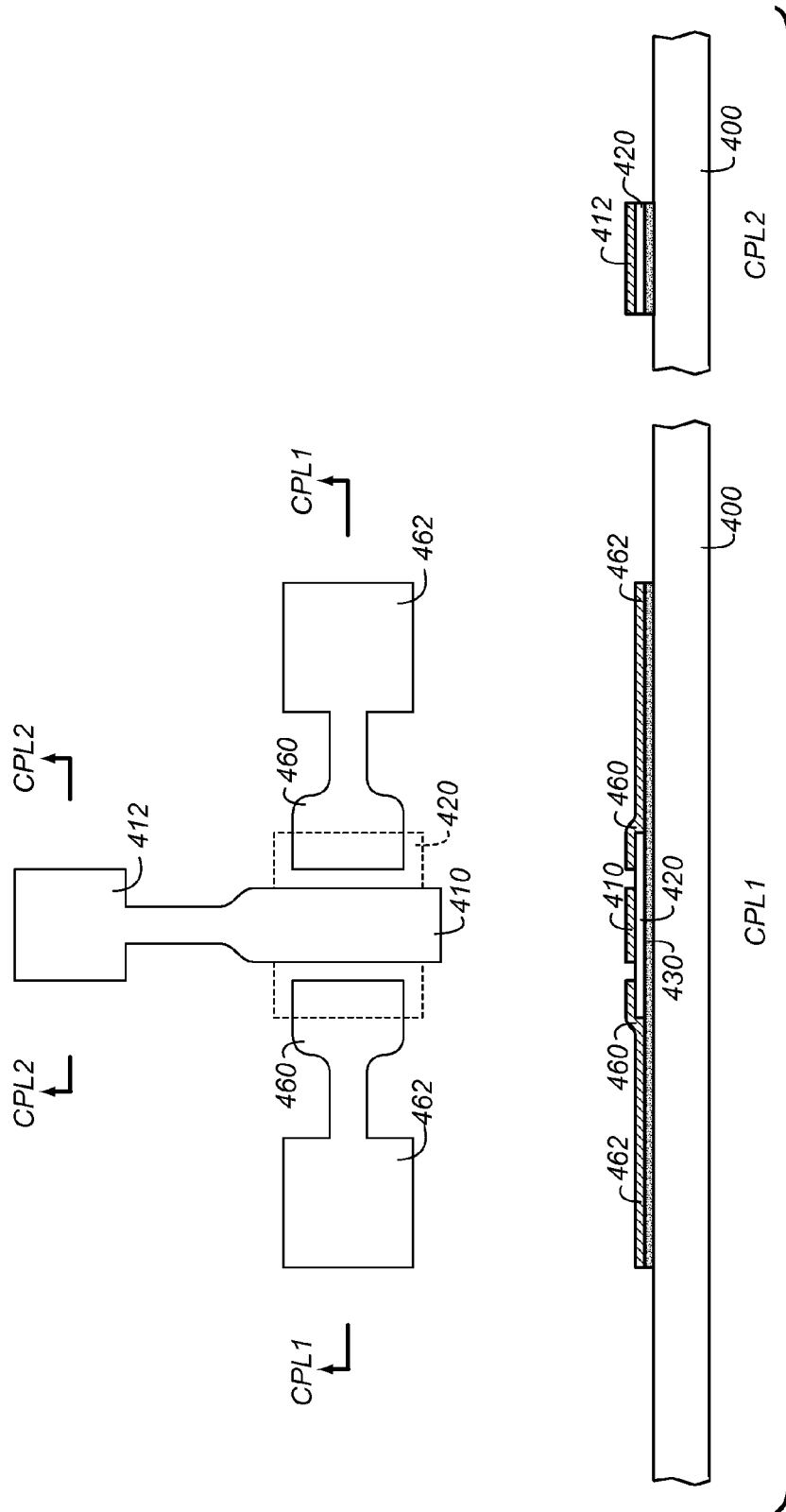


FIG. 4D

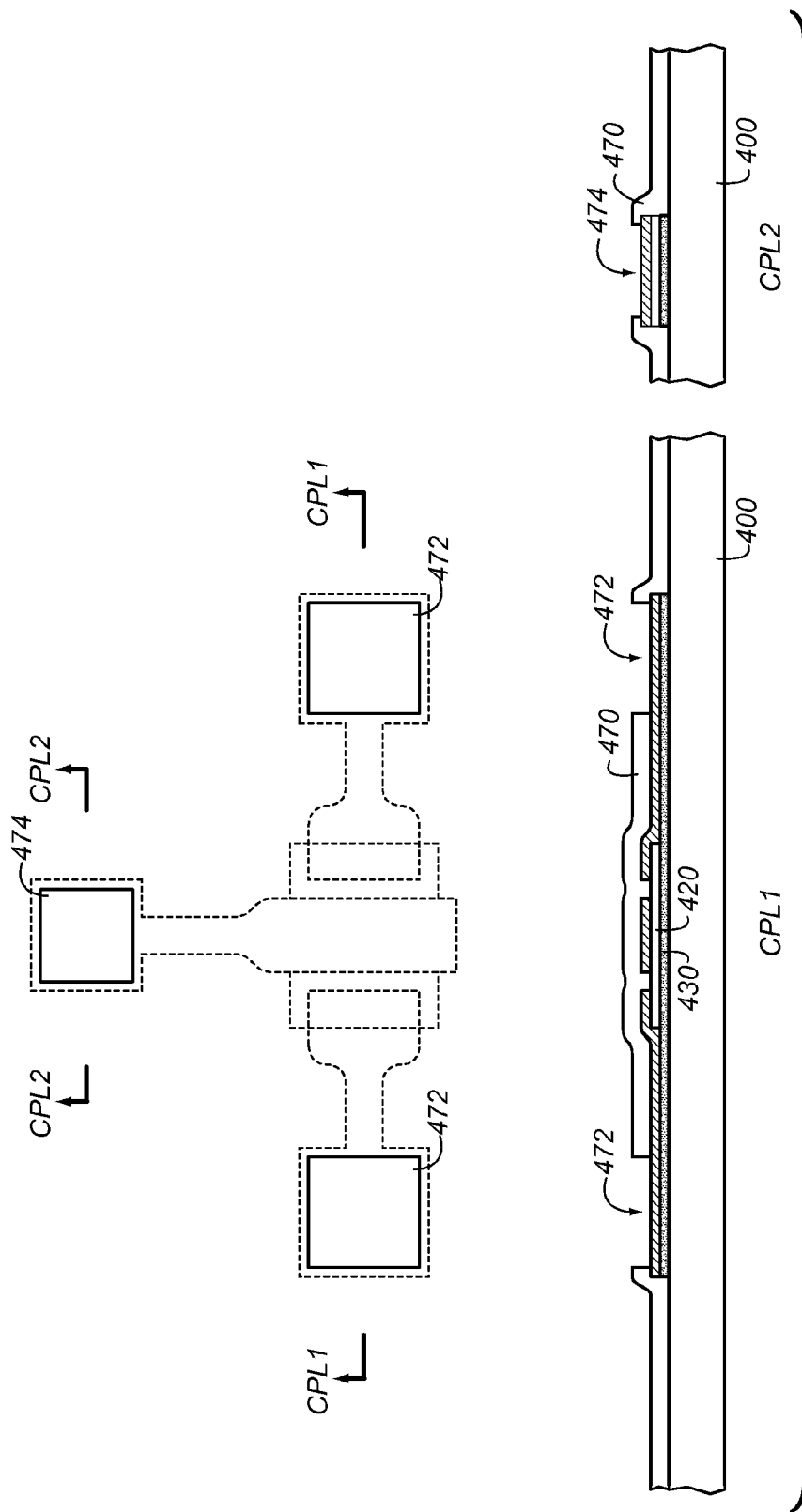


FIG. 4E

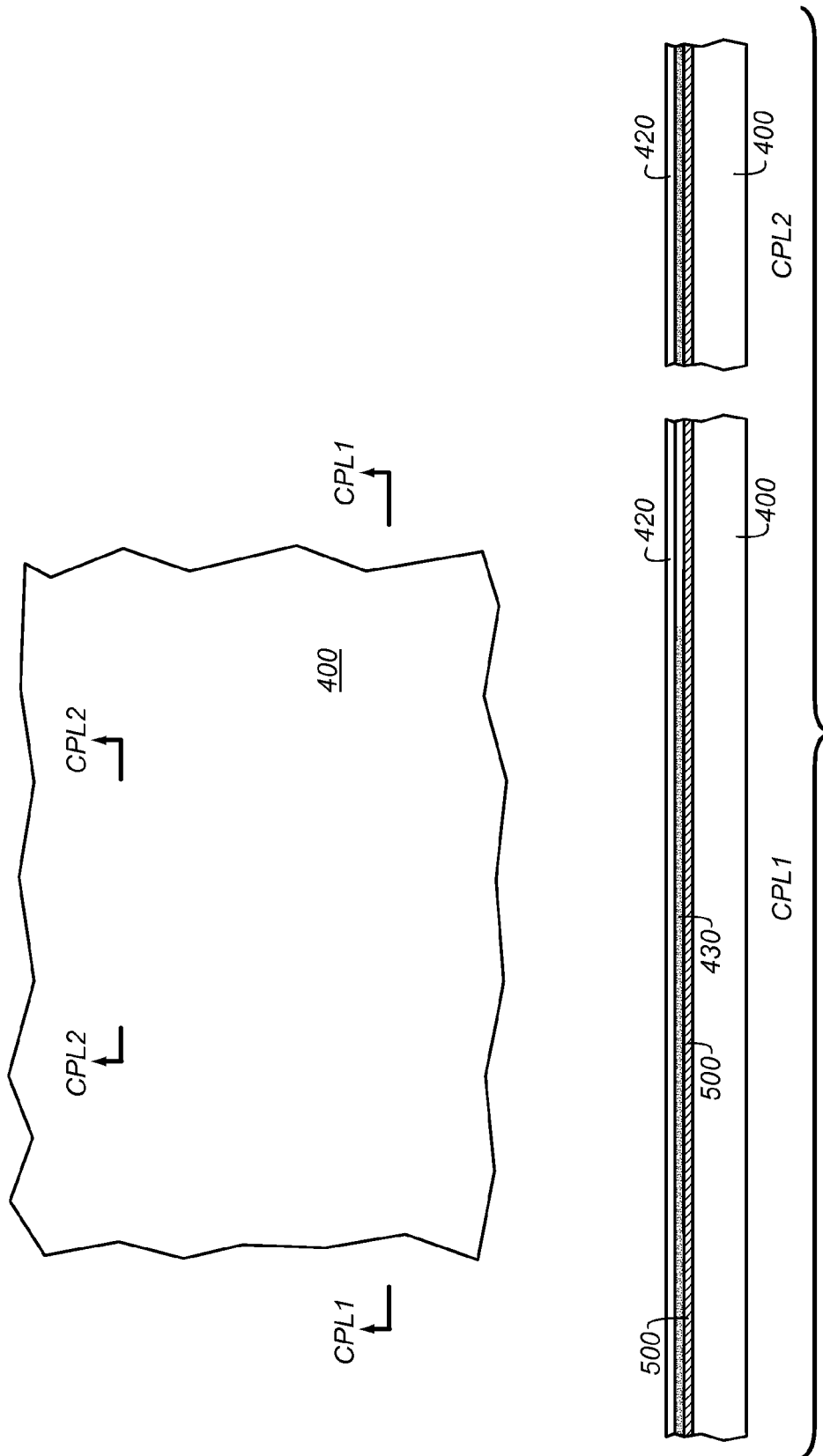


FIG. 5A

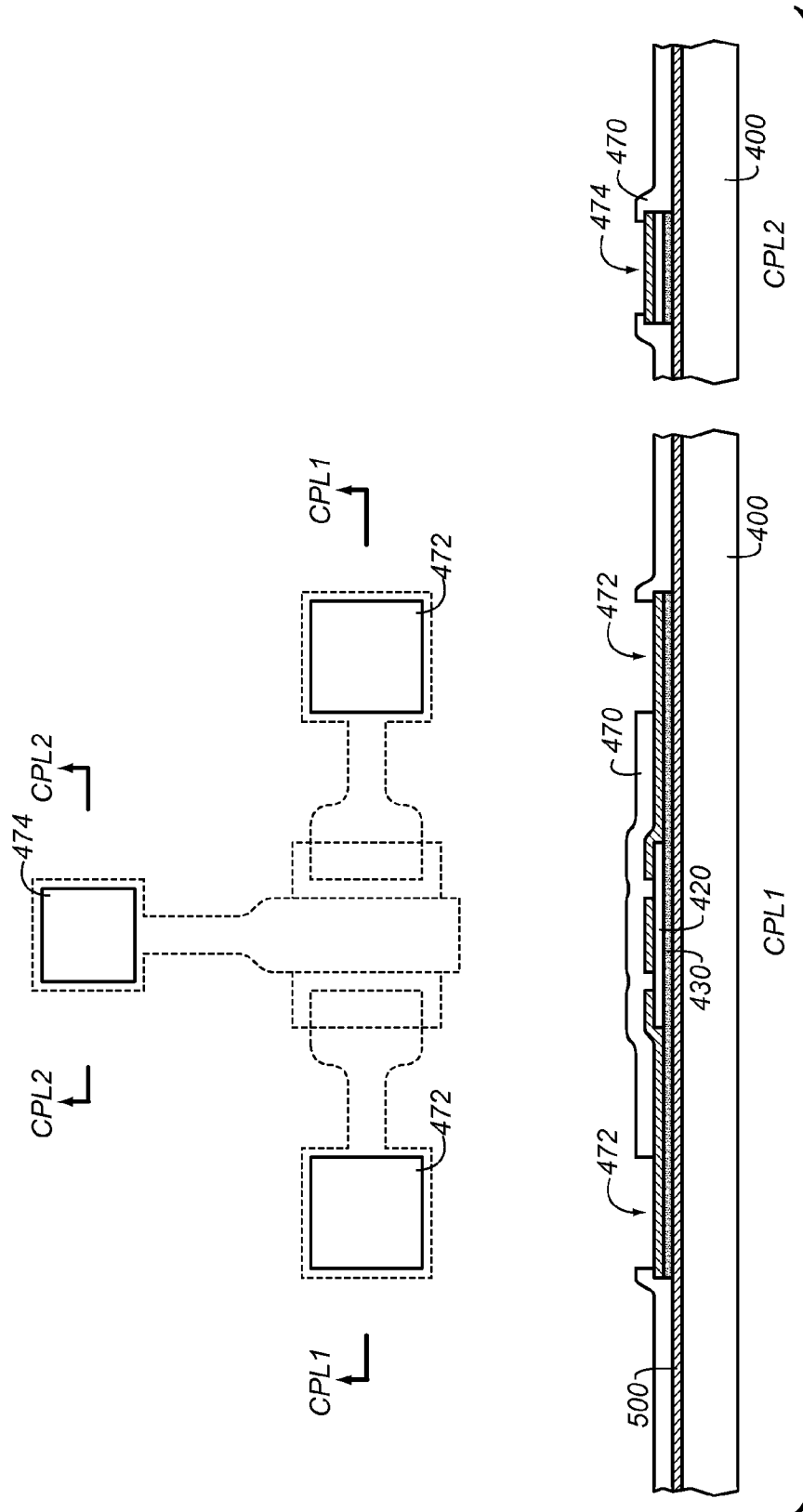
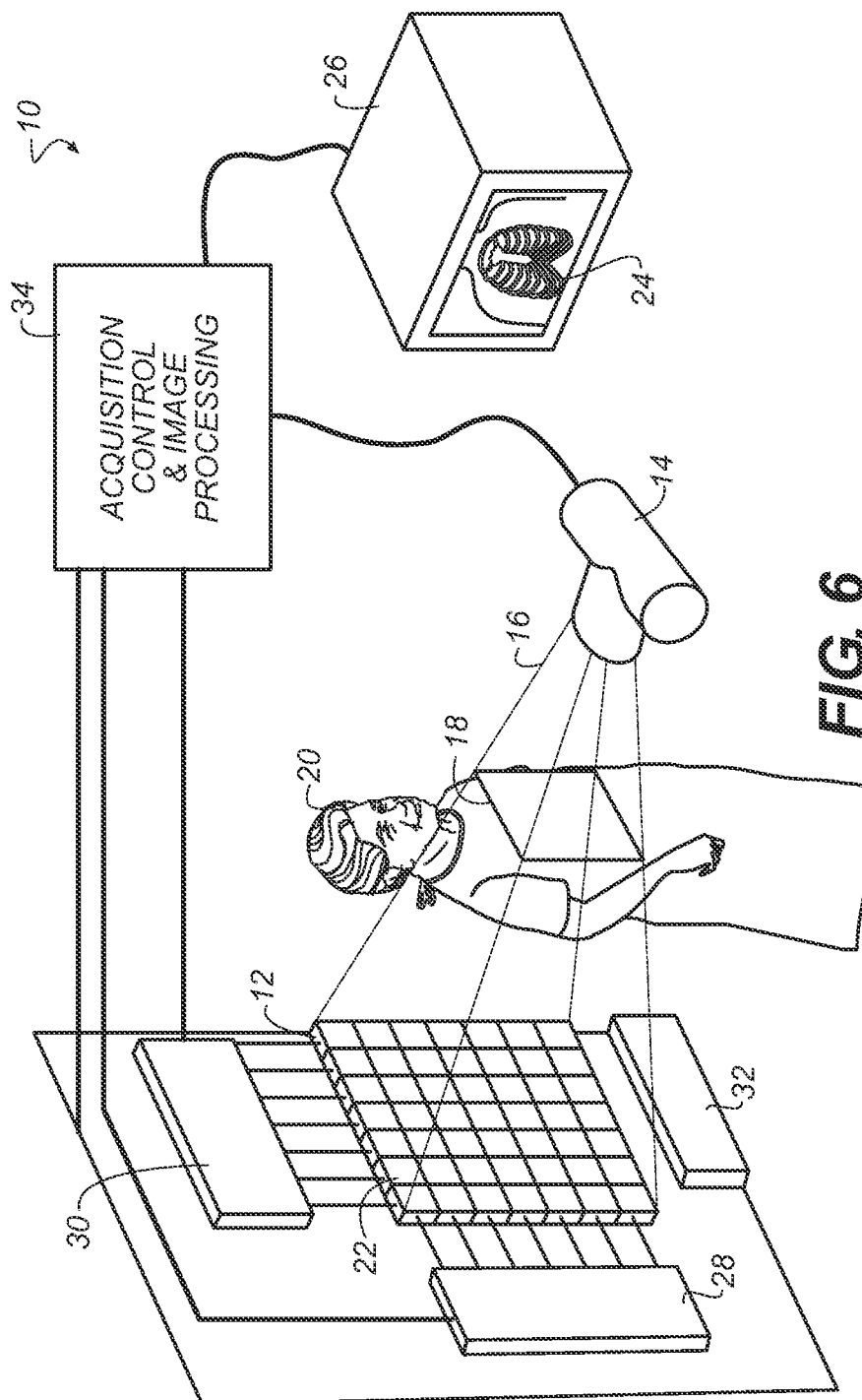


FIG. 5B



RADIOGRAPHIC IMAGING ARRAY FABRICATION PROCESS FOR METAL OXIDE THIN-FILM TRANSISTORS WITH REDUCED MASK COUNT

FIELD OF THE INVENTION

The invention relates generally to the field of radiation conversion apparatus, and in particular to medical radiographic imaging and digital radiographic (DR) detectors, and more particularly to fabrication processes for thin-film transistors (TFTs) using non-single crystalline semiconductor materials such as disordered metal-oxide semiconductor as an active layer.

BACKGROUND

Thin-film transistors (TFT) are used as one of the fundamental building blocks for current large-area electronics. Amorphous silicon (a-Si) TFTs usually serve as electrical switches for large-area liquid-crystal displays (LCD) and large-area flat-panel imagers (FPD); they are well known in the art of large-area electronics fabrication. A typical TFT has three terminals: gate, source, and drain. A majority of the charge carriers flow between the source and drain terminal through a semiconducting layer (referred to as an active layer). The degree of conduction of the semiconducting layer between the source and drain terminal is controlled by the potential of the gate terminal. The source and drain terminal is usually identified by the type carrier responsible for the main conduction current flow. Further, the TFTs can be made geometrically symmetric and therefore the distinction between source and drain is only made by its electrical potential difference and the type of charge carrier the transistor uses for conduction. Therefore, the two terminals are often referred together as the source/drain (SD) terminals. For the purpose of this application, the source and drain terminals are not separately identified to be distinct, but that is not intended to limit the scope of the application.

For large size radiographic imaging arrays, TFTs are typically used as a switching element in pixels within a radiographic imaging array. To those of ordinary skill in the art, it is immediately evident that there are numerous other possible choices for the switching elements as well as types of materials that can compose the elements. There is a need to improve performance characteristics of TFTs included in large-size radiographic imaging arrays, digital radiographic (DR) detectors and methods for using the same.

SUMMARY OF THE INVENTION

An aspect of this application is to advance the art of medical digital radiography.

Another aspect of this application to address in whole or in part, at least the foregoing and other deficiencies in the related art.

It is another aspect of this application to provide in whole or in part, at least the advantages described herein.

An aspect of this application is to provide methods and/or apparatus to address and/or reduce disadvantages caused by the use of portable (e.g., wireless) digital radiography (DR) detectors and/or radiography imaging apparatus using the same.

An aspect of this application is to provide radiographic imaging apparatus and/or methods for making the same that

can reduce a number of processing operations or use a lower photolithography mask count in a fabrication process for TFT.

An aspect of this application is to provide radiographic imaging apparatus and/or methods that can use smaller alignment tolerances for TFTs or reduce alignment tolerances between TFT electrodes.

An aspect of this application is to provide radiographic imaging apparatus fabrication process that can reduce photolithography mask counts or photolithography mask steps for TFT devices, require lower alignment tolerances between the TFT electrodes, and/or use a reduced thickness active layer in TFT devices.

An aspect of this application is to provide radiographic imaging methods and/or apparatus that can reduce parasitic capacitances than can hinder the dynamic performance of TFT devices used in a radiographic imaging array.

In accordance with one embodiment, the present invention can provide a method of manufacturing a digital radiographic detector, the radiographic detector including an imaging array comprising a plurality of pixels arranged in rows and columns, each pixel including a photosensor configured to generate a signal based upon radiation received, the method can include forming an insulating substrate; forming a thin-film transistor in each of the plurality of pixels coupled to a photosensor, including, forming a metal-oxide semiconductor active layer and a gate insulator layer over the insulating substrate, patterning the gate insulator layer using a first photolithography mask, forming a conductive layer comprising metal over the gate insulator layer and selected exposed portions of the metal-oxide semiconductor active layer, patterning the conductive layer using a second photolithography mask to form control electrode, first electrode and second electrode, forming a protective layer over the electrodes and the exposed gate insulator layer, and patterning the protective layer using a third photolithography mask to expose a portion of the electrodes for electrical connection.

In accordance with one embodiment, the present invention can provide a digital radiographic area detector that can include a housing configured to include an upper surface, a lower surface, and side surfaces to connect the upper surface and the lower surface; an insulating substrate inside the housing; an imaging device mounted inside the housing on the insulating substrate, the imaging device comprising a plurality of pixels, each pixel comprising at least one electrically chargeable photosensor and at least one thin-film transistor (TFT); a bias control circuit to provide a bias voltage to the photosensors for a portion of the imaging array; an address control circuit to control scan lines, where each of the scan lines is configured to extend in a first direction and is coupled to a plurality of pixels in the portion of the imaging array; and a signal sensing circuit connected to data lines, where each of the data lines is configured to extend in a second direction and is coupled to at least two pixels in the portion of the imaging array; where the at least one TFT comprises a metal oxide semiconductor active layer and a co-planar gate electrode, source electrode and drain electrode positioned in a single identical conductive metal layer.

These objects are given only by way of illustrative example, and such objects may be exemplary of one or more embodiments of the invention. Other desirable objectives and advantages inherently achieved by the disclosed invention may occur or become apparent to those skilled in the art. The invention is defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more

particular description of the embodiments of the invention, as illustrated in the accompanying drawings.

The elements of the drawings are not necessarily to scale relative to each other.

FIGS. 1A-1G are diagrams that show top-down views and cross-sectional views of processing operations for a conventional BCE inverted-staggered TFT architecture.

FIG. 2 is a diagram that shows top-down views and cross-sectional views of another conventional BCE inverted-staggered TFT architecture.

FIGS. 3A-3G are diagrams that show top-down views and cross-sectional views of processing operations for a conventional coplanar TFT architecture.

FIGS. 4A-4E are diagrams that show top-down views and cross-sectional views of processing operations for a manufacturing method embodiment of a radiographic imaging array according to the application.

FIGS. 5A-5B are diagrams that respectively show top-down views and cross-sectional views of processing operations for another manufacturing method embodiment of a radiographic imaging array according to the application.

FIG. 6 is a diagram that shows a perspective view of a radiographic imaging apparatus including an area detector according to the application used for a radiographic procedure.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

The following is a description of exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

For simplicity and illustrative purposes, principles of the invention are described herein by referring mainly to exemplary embodiments thereof. However, one of ordinary skill in the art would readily recognize that the same principles are equally applicable to, and can be implemented in, all types of radiographic imaging arrays, various types of radiographic imaging apparatus and/or methods for using the same and that any such variations do not depart from the true spirit and scope of the application. Moreover, in the following description, references are made to the accompanying figures, which illustrate specific exemplary embodiments. Electrical, mechanical, logical and structural changes can be made to the embodiments without departing from the spirit and scope of the invention. In addition, while a feature of the invention may have been disclosed with respect to only one of several implementations/embodiments, such feature can be combined with one or more other features of other implementations/embodiments as can be desired and/or advantageous for any given or identifiable function. The following description is, therefore, not to be taken in a limiting sense and the scope of the invention is defined by the appended claims and their equivalents.

Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements. Moreover, all ranges disclosed herein are to be understood to encompass any and all sub-ranges subsumed therein. Where they are used, the terms "first", "second", and so on, do not necessarily denote any ordinal or

priority relation, but may be used for more clearly distinguishing one element or time interval from another.

There are a number of transistor architectures used for radiographic imaging and each has corresponding advantages. The most widely used TFT architecture in the large-area electronics industry is the back-channel etch (BCE) inverted-staggered TFT.

FIGS. 1A-1G shows a typical fabrication process of the BCE inverted-staggered TFT architecture. The BCE inverted-staggered TFT process is often used for fabricating hydrogenated amorphous silicon (a-Si:H) TFTs. The BCE inverted-staggered TFT architecture is sometimes referred to as the bottom-gate architecture because a gate electrode **110** is formed in closer proximity to an insulating substrate **100** than an active semiconductor layer **130**. FIGS. 1A-1G show device top views and device cross sections, respectively, for the described processing steps. CPL1 and CPL2 indicate the cutting-planes used for the cross-sections. CPL1 shows the device cross-sectional diagram for the TFT and the SD probe pads while CPL2 shows the cross-sectional diagram for the gate probe pad.

Referring to FIG. 1A, a metal layer for the gate electrode **110** that controls the electrical conductivity of the active semiconductor island is first deposited on an electrically insulating substrate **100**. The metal layer is patterned by a photolithography mask as known in the art to form the gate electrode **110** and part of the gate probe pad **112** for the TFT gate terminal. The resulting structure is shown in FIG. 1A.

Referring to FIG. 1B, an insulating layer **120**, an active semiconductor layer **130**, and a contact layer (e.g., doped semiconductor layer) **140** are then consecutively deposited over the substrate **100** to cover the patterned gate electrode **110** and portions of the gate probe pad **112**. This step is sometimes referred to as the "tri-layer deposition step" well known in the art. The deposited insulator layer **120** is also referred to as the gate insulator layer or the gate dielectric layer. The insulator layer **120** is important as the gate electrode **110** must not be in direct contact with the active semiconductor layer **130**. One skilled in the art of TFT fabrication would also recognize the importance of consecutive deposition of the tri-layer structure to reduce or minimize interface defects between the layers **120**, **130**, **140**. Consecutive deposition can be especially relevant to the interface between the gate insulator layer **120** and the active semiconductor layer **130** as the interface quality (e.g., interface defects) can significantly affect the performances of the resulting TFT. The resulting structure after this fabrication step is shown in FIG. 1B. For clarity, both the active semiconductor layer **130** and the contact layer **140** are omitted from the top view in FIG. 1B.

The active semiconductor layer **130** and the doped contact layer **140** are then patterned using a second photolithography mask to form the active semiconductor island as shown in FIG. 1C. The active semiconductor island is usually aligned to the gate electrode **110**. For clarity, the doped contact layer **140** is omitted in the top view shown in FIG. 1C because the doped contact layer **140** edges overlap the active semiconductor layer **130**. At this stage, the gate insulator layer **120** can be patterned to open a probe pad window for the gate electrode **150** using a third photolithography mask as shown in FIG. 1D by the cross-section along CPL2.

Referring to FIG. 1E, the source and drain electrodes **160** of the TFT are then formed by depositing a second metal layer across the entire substrate covering previously formed features then followed by photolithography using a fourth mask. The source and drain probe pads **162** are also formed during using the second metal layer as shown in FIG. 1E. The second

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metal layer is patterned such that near the region of the gate electrode probe pad **112**, metal also exists (e.g., remains) and completely covers the gate electrode probe pad window **150** to provide an electrical connection between the first patterned metal layer and the second patterned metal layer. The combination of the two metal layers (e.g., first patterned metal layer and the second patterned metal layer) forms the gate electrode probe pad **112** as shown by cross-section along CPL2 in FIG. 1E.

After patterning the second metal layer to form the source and drain electrodes, a selective etch process is performed to completely remove the doped contact layer **140** in regions not covered by the source drain metal, which includes the region between the source and drain terminals **160** usually referred to as the channel region. To guarantee complete removal of the doped contact layer **140** in the channel region, the active semiconductor layer **130** not covered by the source and drain electrode **160** is partially etched as well thereby forming a shallow trench. The shallow trench in the channel region causes the thickness of the active semiconductor material underneath the source and drain electrodes **160** to be different than the thickness of the active material in the channel region (and in other regions of the active island not covered by the second metal layer). This is as shown by cross-section along CPL1 in FIG. 1F and this selective etch process step is commonly referred to as BCE process; thus, giving the TFT architecture the name BCE inverted-staggered TFT.

Referring to FIG. 1G, the resulting structure is often encapsulated by a thick encapsulation layer **170** to prevent undesirable effects caused by ambient environmental conditions. The encapsulation layer **170** is deposited across the entire substrate **100** covering previously formed features. The encapsulation layer **170** also serves as a passivation layer to mediate damage caused by the BCE process. Since the encapsulation layer **170** is also an electrical insulator, portions of the encapsulation layer **170** must be removed in probe pad or contact window areas using a fifth photolithography mask in order to provide or obtain electrical contact with the TFT terminals. The resulting structure is shown in FIG. 1G where the gate probe pad window **174** and source and drain probe pad windows **172** are formed by etching away the passivation layer **170** in these regions. At this point, the BCE inverted-staggered TFT fabrication process is complete and it is noted that a total of five photolithography masks are used.

Use of the third photolithography mask/step shown in FIG. 1D can be optional when the gate dielectric material **120** can be etched along with the passivation layer **170** etch. When the third photolithography mask is omitted and the gate electrode probe pad contact window **174** is etched by the fifth photolithography mask, then resulting structure is shown in FIG. 2. For the structure shown in FIG. 2, the total number of photolithography masks is reduced to four.

The BCE TFT fabrication process introduces a number of constraints to the active semiconductor layer **130** properties. The BCE TFT fabrication process sacrifices the flexibility of the active semiconductor layer **130** options to reap the benefit of a reduced mask count. One constraint is the thickness of the active layer. When the active layer **130** is too thin, there is only a small timing window during the BCE fabrication process before the active layer is completely etched though (e.g., in the channel region); under such circumstances no transistor action would occur for the fabricated structure. However, a thinner active layer **130** is preferred because a thicker active layer can lead to higher resistances and/or reduce the apparent carrier mobility. Another constraint is the etch selectivity between the active semiconductor layer **130** and the source/drain (SD) electrode metal layer material. For the BCE TFT

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fabrication process, the etch selectivity needs to be sufficiently high; otherwise, the active island material can be completely removed even prior to the BCE process during the patterning of the source and drain electrodes **160** (process step illustrated in FIG. 1E). Thus, the BCE TFT fabrication process can not use metal oxide semiconductors, such as amorphous indium gallium zinc oxide (a-IGZO) as the active layer **130**. Since a-IGZO reacts with many metal etchants, a desired high etch selectivity can not be achieved during the patterning for the source and drain metal layer. To address the high etch selectivity requirement, an additional protective layer can be introduced prior to the patterning of the SD electrode metal. The additional protective layer is also often referred to as an etch-stopper (ES) layer because it operates to reduce or prevent the etching agent used for patterning the SD metal from attacking the active layer **130**. However, for the inverted-staggered TFT architectures, the introduction of the ES layer requires the use of at least one additional photolithography mask to pattern the ES layer. Another constraint placed by the BCE fabrication process is that the active semiconductor layer **130** must be sufficiently thick. The thickness of the active semiconductor layer **130** not only must allow for process tolerances during the back-channel etch, but also must ensure satisfactory step coverage over the topology introduced by the underlying gate electrode **110**.

The constraint issues described above can be avoided using a coplanar TFT architecture. For coplanar TFTs, the active semiconductor layer **130** is formed prior to forming the gate electrode **110**. Forming the active semiconductor layer **130** before the gate electrode **110** can avoid the active semiconductor layer **130** having to traverse through the topology introduced by the gate electrode **110**. Further, the insulator layers deposited prior to metal patterning can also function as an ES layer, which can relax the constraints placed on the active layer **130**. To illustrate this, a typical coplanar metal oxide TFT process is shown FIGS. 3A-3F.

Referring to FIG. 3A, the active layer **130**, the gate insulator layer **120**, and the gate metal layer **300**, are initially deposited over an insulating substrate **100**. The resulting structure after this fabrication step is shown in FIG. 3A. The three deposited layers are omitted in the top-down view in FIG. 3A for clarity. Then, using a first photolithography mask, the gate metal layer **300** is patterned to form the gate electrode **110** and the gate probe pad **112**. The resulting structure after this fabrication step is shown in FIG. 3B. Since the gate insulator layer **120** is covering the active layer **130** completely during the formation of the gate electrode **110**, the active layer material is not attacked by the etching agent for the gate metal layer **300**. The active layer **130** and the gate insulator layer **120** are again omitted in the top view in FIG. 3B for clarity because they both cover the entire insulating substrate **100**.

Referring to FIG. 3C, the gate insulator layer **120** is patterned using a self-aligned process, which exposes the active layer material **130** in areas not covered by the gate metal material **300**. The resulting structure after this fabrication step is shown in FIG. 3C where the active layer **130** covering the entire insulating substrate **100** is omitted in the top view. Then, using a second photolithography mask, the active layer **130** is patterned to form the transistor active island. The resulting structure after this fabrication step is shown in FIG. 3D. The active layer is then protected by depositing a passivation layer **320** across the entire substrate **100** covering all the previously formed features. The passivation layer **320** must be electrically insulating as otherwise, the passivation layer **320** would form an electrical connection between the gate electrode **110** and the active island. Then, the passivation

layer **320** is patterned using a third photolithography mask to open contact windows **310** for preparation in connecting the source and drain electrodes **160** to the active layer **130** and to open gate probe pad window **150**. The resulting structure after this fabrication step is shown in FIG. **3E**.

Next, referring to FIG. **3F**, the source and drain metal layer is deposited across the entire substrate **100** covering all the previously formed features. This metal layer is then patterned using the fourth photolithography mask to form the source and drain electrodes **160**, and the source and drain probe pads **162**. Similar to the inverted-staggered TFT architecture, a portion of this metal layer is also left covering the gate probe pad window **150** after patterning. The source and drain electrode metal and the gate electrode metal are electrically connected and together referred to as the gate probe pad **112**. The resulting structure after this fabrication step is shown in FIG. **3F**. Finally, a blanket passivation layer **170** is formed over the substrate **100** covering all the previously formed features. The passivation layer **170** must also be electrically insulating because otherwise the source and drain terminals **160** would be electrically connected and no transistor action would occur for the fabricated features. In order to make electrical contact to the gate, source, and drain terminals of the coplanar TFT, the electrically insulating layer **170** is patterned by a fifth photolithography mask to open contact windows for the source and drain probe pad windows **172** and the gate probe pad window **174**. The resulting structure after this fabrication step is shown in FIG. **3G**. At this point, the fabrication process is complete and a total of five photolithography masks used. As shown in the cross-sectional view of FIG. **3G**, since the remaining active layer **130** conforms to the substrate **100** surface, the remaining active layer **130** is not subjected to any step covering issue (e.g., caused by the gate electrode **110**) as in the inverted-staggered TFT architecture. Since the substrate **100** surface is also relatively smooth and planar, excellent uniformity in the remaining active layer **130** can be achieved, which directly leads to the ability to deposit thinner active layer material, especially in large area arrays. The ability to deposit thinner active layer material is further aided in the coplanar TFT by the absence of the BCE process for the active layer **130**. However, compared with the inverted-staggered TFT architecture shown in FIG. **2**, the coplanar TFT architecture shown in FIG. **3G** requires one additional mask. The additional mask requirement is caused by the via windows used to contact and electrically connect the source and drain electrodes **160** to the active layer **130**.

There is a general desire to reduce the number of photolithography masks required in fabrication processes because reducing the number of masks can variously cause the reduction of manufacturing costs. The reduction of manufacturing cost stems from several aspects of the fabrication process. First, the reduction of photolithography masks often leads to the reduction of processing operations or processing steps. As each processing operation requires certain amount of time, reducing the number of operations required can lead to more devices fabricated per unit time, which significantly impacts/reduces the manufacturing cost especially when fabricating in large volumes. Second, it is well known in the TFT fabrication art that prescribed amount or a certain amount of miss-alignment is expected and occurs between photolithography steps. Therefore, the photolithography masks are designed with an alignment margin (e.g., built in tolerances) sufficient to handle the misalignment and ensure device functionality. Design rules are commonly used to refer to feature spacing tolerance within a photolithographic mask or alignment margins in a photolithographic mask sufficient to address and ensure device operability (e.g., electrical contact/

insulation between features formed by different masks) between separate photolithography operations in manufacturing a resulting device. As the number of photolithography steps or photolithography masks increase, the total amount of misalignment margin, or acceptable tolerance to misalignment that still yields functional devices, can also increase, which can cause larger TFT and/or resulting device size. Reduction in the mask count can cause the reduction of total alignment tolerances required and may consequently lead to smaller TFT and/or resulting device areas. Since smaller device area leads to more devices fabricated per unit area, manufacturing cost can be lowered by not only reduction in time allocated for the mask alignment, but also smaller total alignment tolerance. Misalignment of the photolithography masks also increases the number of non-functional devices, which reduces the manufacturing yield. The probability of mask misalignment increases with higher mask count; therefore, reducing the mask count also improves manufacturing yield, which can further reduce of manufacturing cost.

In certain exemplary embodiments, an active layer **430** material can be amorphous indium gallium zinc oxide (a-IGZO) semiconductor. To those of ordinary skill in the art, it is evident that there are numerous other possible choices for the active layer **430** material as well as types of materials of which the active layer can be composed and/or include. One of ordinary skill in the art would readily recognize that the same principles are equally applicable to, and can be implemented in, all types of radiographic imaging arrays and/or methods therefore and that any such variations do not depart from the true spirit and scope of exemplary embodiments according to the application.

FIG. **4A** to FIG. **4E** illustrate top-down views and cross-sectional views of selected processing operations, respectively, for some exemplary method embodiments of forming a thin-film transistor. As shown in FIGS. **4A-4E**, CPL1 and CPL2 are cutting-planes lines used to indicate where device cross-sections are drawn. CPL1 illustrates device cross-sectional diagram positions for the TFT and the SD probe pads, and CPL2 illustrates cross-sectional diagram positions for the gate probe pad. For some top-down views in FIGS. **4A-4E**, layers are omitted for clarity when the layers are deposited across the entire device or an entire substrate. The cross-sectional views in FIGS. **4A-4E**, however, still illustrate the layers omitted for some top-down views.

In one exemplary embodiment, referring to FIG. **4A**, a process can commence with the deposition of an active layer **430** and a gate insulator layer **420** on top of/over an insulating substrate **400**. In one embodiment, the active layer **430** can be an a-IGZO layer. The gate insulator layer can be an insulating layer such as those comprised of silicon dioxide (SiO₂) or multiple layers of electrically insulating material such as amorphous silicon nitride (a-SiN), or combinations thereof. The insulating substrate can be a single or multiple layers of materials such as, but not limited to, glass, polyimide, plastic or the like.

Exemplary active layers (e.g., active layer **430**) used in certain exemplary TFT embodiments can also be composed of a layer of metal-oxide semiconductor or multiple layers of metal-oxide semiconductor. Exemplary active layers (e.g., active layer **430**) can also include various types of metal oxide-based semiconductor materials. Further, amorphous or polycrystalline oxide-based semiconductor materials can be used for the active layers. Any conductive semiconductor material that is sensitive to metal etch can be used for the active layers described herein (e.g., active layer **430**).

The surface (e.g., the insulating layer **400**) adjacent to the active layer **430** can be planar and/or can have relatively low

surface roughness. The gate insulator layer **420** and the active layer **430** can preferably be formed consecutively without breaking vacuum, which can improve an interface quality and consequently, can improve electrical properties of the TFT. As shown in FIG. **4B**, using a first photolithography mask, the gate insulator layer **420** can be patterned. The patterned insulator layer **420** can function not only as an etch-stopper, but also function as a gate dielectric. The resulting configuration features can be shown in FIG. **4B**.

As shown in FIG. **4C**, a metal layer **450** can be deposited over the entire substrate **400**, covering all the previously formed features; this is shown in FIG. **4C**. The metal layer **450** can provide materials used for the gate electrode **410**, but also used for source and drain electrodes **460** as well as materials used for corresponding gate probe pads **412** and source and drain probe pads **462**. The metal layer **450** can be a combination of a metal layer or multiple metal layers together with various elements to improve layer/performance characteristics such as conductivity.

As shown in FIG. **4D**, the metal layer **450** can then be patterned using a second photolithography mask to form the gate electrode **410**, the source and drain electrodes **460**, the gate probe pad **412**, and the source and drain probe pads **462**. Since the etchant for the metal layer **450** also sufficiently attacks the metal oxide semiconductor layer **430**, regions of the active layer **430** not covered by the etch-stopper and the metal material **450** can both be removed (e.g., completely) during the second photolithography mask patterning process. The resulting configuration features can be shown in FIG. **4D**.

Then, a protective layer (e.g., passivation layer) **470** can be formed across the entire substrate **400**, covering all the previously formed features. The passivation layer **470** can preferably be electrically insulating since otherwise, the passivation layer **470** would electrically connect the terminals of the TFT, rendering the device non-functional or inoperative. In certain exemplary embodiments, to provide electrical coupling or contact the TFT terminals, a third photolithography mask can be used to open the probe pad windows for the source and drain terminals **472**, as well as the gate terminals **474**. The resulting configuration features can be shown in FIG. **4E**. Compared to the inverted staggered TFT architecture described herein in FIGS. **1A-1G** and the coplanar TFT architecture described herein in FIGS. **3A-3G**, which each use five photolithography masks, certain exemplary embodiments described herein can use only three photolithography masks.

In addition to reduced photolithography mask count, certain exemplary embodiments described herein can also allow or provide for tighter tolerances for misalignment. Exemplary embodiments can provide tighter tolerances at least because all transistor electrodes or all three TFT electrodes can be patterned using a single or the same photolithography mask. Further, since alignment tolerances between different photolithography masks or patterning operations can be larger than the spacing tolerance for a single photolithography mask or patterning operation, at least spacing between the electrodes of a transistor can be made much smaller.

In some exemplary embodiments, an active material (e.g., active layer **430**) can be very sensitive to processing conditions and sometimes, contaminants from the substrate **400** can migrate into the active layer causing undesirable effects. FIGS. **5A-5B** are diagrams that respectively illustrate top-down views and cross-sectional views of selected processing operations for another exemplary method embodiment of forming a thin-film transistor for a radiographic imaging array of a DR detector. As shown in FIG. **5A**, a suitable barrier layer **500** can be inserted between the insulating substrate **400**

and the active layer **430**. FIG. **5A** shows a processing operation where the barrier layer **500**, the active layer **430**, and the gate insulator layer **420** can be deposited consecutively on the insulating substrate before patterning the gate insulator layer **420**. The barrier layer can also be composed of, for example, SiO₂, which not only provides good interface properties with the active layer **430** but also can reduce or prevent diffusion of unwanted contaminants from the insulating substrate **400** into the active layer **430**. After similar process operations disclosed with respect to FIGS. **4A-4E** are performed, the resulting configuration features are shown in FIG. **5B**.

Embodiments of radiographic imaging systems, radiographic detectors and/or methods for using the same have various advantages. For example, embodiments can provide TFT for radiographic imaging apparatus having increased or improved performance characteristics.

FIG. **6** is a diagram that shows a perspective view of an exemplary radiographic area detector configured to include rows and columns of detector cells in position to receive X-rays passing through a patient during a radiographic procedure. As shown in FIG. **6**, an X-ray system **10** that can use an area array **12** can include an X-ray tube **14** collimated to provide an area X-ray beam **16** passing through an area **18** of a patient **20**. The beam **16** can be attenuated along its many rays by the internal structure of the patient **20** to then be received by the detector array **12**, which can include certain exemplary embodiments of a thin-film transistor described herein, and that can extend generally over a prescribed area (e.g., a plane) perpendicular to the central ray of the X-ray beam **16** (e.g., normal medical imaging operations).

The array **12** can be divided into a plurality of individual cells **22** that can be arranged rectilinearly in columns and rows. As will be understood to those of ordinary skill in the art, the orientation of the columns and rows is arbitrary, however, for clarity of description it will be assumed that the rows extend horizontally and the columns extend vertically.

In exemplary operations, the rows of cells **22** can be scanned one (or more) at a time by scanning circuit **28** so that exposure data from each cell **22** can be read by read-out circuit **30**. Each cell **22** can independently measure an intensity of radiation received at its surface and thus the exposure data read-out can provide one pixel of information in an image **24** to be displayed on a display **26** normally viewed by the user. A bias circuit **32** can control a bias voltage to the cells **22**.

Each of the bias circuit **32**, the scanning circuit **28**, and the read-out circuit **30** (e.g., Read Out Integrated Circuits (RO-ICs)), can communicate with an acquisition control and image processing circuit **34** that can coordinate operations of the circuits **30**, **28** and **32**, for example, by use of an electronic processor (not shown). The acquisition control and image processing circuit **34**, can also control the examination procedure, and the X-ray tube **14**, turning it on and off and controlling the tube current and thus the fluence of X-rays in beam **16** and/or the tube voltage and hence the energy of the X-rays in beam **16**.

The acquisition control and image processing circuit **34** can provide image data to the display **26**, based on the exposure data provided by each cell **22**. Alternatively, acquisition control and image processing circuit **34** can manipulate the image data, store raw or processed image data (e.g., at a local or remotely located memory) or export the image data.

Examples of image sensing elements used in image sensing arrays **12** include various types of photoelectric conversion devices (e.g., photosensors) such as photodiodes (P-N or PIN diodes), photo-capacitors (MIS), or photoconductors. Examples of switching elements used for signal read-out

include exemplary embodiments of thin-film transistors described herein, MOS transistors, bipolar transistors, or FETs.

In an exemplary a-IGZO based indirect flat panel imager, incident X-ray photons are down-converted to lower energy photons, which can be subsequently converted to electron-hole pairs within a-Si NIP photodiodes. The pixel charge capacity of the photodiodes can be a product of the bias voltage and the photodiode capacitance. In general, a reverse bias voltage is applied to the bias lines to create an electric field (e.g., and hence a depletion region) across the photodiodes and enhance charge collection efficiency. The image signal can be integrated by the photodiodes while the associated TFTs are held in a non-conducting ("off") state, for example, by maintaining the gate lines at a negative voltage. A radiographic imaging array can be read out by sequentially switching rows of the TFTs to a conducting state using TFT gate control circuitry. When a row of pixels is switched to a conducting ("on") state, for example by applying a positive voltage to the corresponding gate line, charge from those pixels can be transferred along data lines and integrated by external charge-sensitive amplifiers. After data is read out, the row can then be switched back to a non-conducting state, and the process is repeated for each row until the entire array has been read out. The signal outputs from the external charge-sensitive amplifiers can be transferred to an analog-to-digital converter (ADC) by a parallel-to-serial multiplexer, subsequently yielding a digital image.

The imaging mode described above applies to static radiographic imaging applications, in which isolated single exposures are obtained. A second operating mode would apply to dynamic imaging applications, in which the radiographic exposure is continuous, such as fluoroscopy. In this operating mode the photodiode reset (a) and the exposure period (b) may be eliminated. The photodiodes are continuously exposed and the charge readout is also performed continuously, with the readout also serving to reset both photodiode and the capacitor.

Exemplary embodiments of radiographic imaging, apparatus, radiographic imaging methods and/or methods for making the same described herein provide various advantages. For example, exemplary embodiments and/or electronic semiconductor devices resulting therefrom can reduce photolithography mask counts or photolithography mask steps for TFT devices, require lower alignment tolerances between the TFT electrodes, use a reduced thickness active layer in TFT devices and/or provide a means of fabricating TFT with very thin active layer.

Although embodiments of the application have been shown with a passive pixel architecture that can include a photosensor and a single TFT for the DR imaging array, various passive pixel structures can be used including but not limited to 2 TFTs, 3 TFTs, or more TFTs with at least one photosensor can be used for the pixel described herein.

Exemplary embodiments herein can be applied to digital radiographic imaging panels that use an array of pixels comprising an X-ray absorbing photoconductor and a readout circuit (e.g., direct detectors). Since the X-rays are absorbed in the photoconductor, no separate scintillating screen is required.

It should be noted that while the present description and examples are primarily directed to radiographic medical imaging of a human or other subject, embodiments of apparatus and methods of the present application can also be applied to other radiographic imaging applications. This includes applications such as non-destructive testing (NDT), for which radiographic images may be obtained and provided

with different processing treatments in order to accentuate different features of the imaged subject.

In certain exemplary embodiments, digital radiographic imaging detectors can include thin-film elements such as but not limited to thin-film photosensors and thin-film transistors. Thin film circuits can be fabricated from deposited thin films on insulating substrates as known to one skilled in the art of radiographic imaging. Exemplary thin-film circuits can include a-IGZO devices such as a-IGZO TFTs or a-Si devices such as a-Si PIN diodes, Schottky diodes, MIS photocapacitors, and be implemented using amorphous semiconductor materials, polycrystalline semiconductor materials such as metal oxide semiconductors. Certain exemplary embodiments herein can be applied to digital radiographic imaging arrays where switching elements include thin-film devices including at least one semiconductor layer. Certain exemplary embodiments herein can be applied to digital radiographic imaging arrays where the DR detector is a flat panel detector, a curved detector or a detector including a flexible imaging substrate.

Embodiments of radiographic imaging systems and methods described herein contemplate methods and program products on any computer readable media for accomplishing its operations. Certain exemplary embodiments according can be implemented using an existing computer processor, or by a special purpose computer processor incorporated for this or another purpose or by a hardwired system.

Consistent with exemplary embodiments, a computer program with stored instructions that perform on image data accessed from an electronic memory can be used. As can be appreciated by those skilled in the image processing arts, a computer program implementing embodiments herein can be utilized by a suitable, general-purpose computer system, such as a personal computer or workstation. However, many other types of computer systems can be used to execute computer programs implementing embodiments, including networked processors. Computer program for performing method embodiments or apparatus embodiments may be stored in various known computer readable storage medium (e.g., disc, tape, solid state electronic storage devices or any other physical device or medium employed to store a computer program), which can be directly or indirectly connected to the image processor by way of the internet or other communication medium. Those skilled in the art will readily recognize that the equivalent of such a computer program product may also be constructed in hardware. Computer-accessible storage or memory can be volatile, non-volatile, or a hybrid combination of volatile and non-volatile types.

It will be understood that computer program products implementing embodiments of this application may make use of various image manipulation algorithms and processes that are well known. It will be further understood that computer program products implementing embodiments of this application may embody algorithms and processes not specifically shown or described herein that are useful for implementation. Such algorithms and processes may include conventional utilities that are within the ordinary skill of the image processing arts. Additional aspects of such algorithms and systems, and hardware and/or software for producing and otherwise processing the images or co-operating with computer program product implementing embodiments of this application, are not specifically shown or described herein and may be selected from such algorithms, systems, hardware, components and elements known in the art.

While the invention has been illustrated with respect to one or more implementations, alterations and/or modifications can be made to the illustrated examples without departing

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from the spirit and scope of the appended claims. The term “at least one of” is used to mean one or more of the listed items can be selected. The term “about” indicates that the value listed can be somewhat altered, as long as the alteration does not result in nonconformance of the process or structure to the illustrated embodiment. Finally, “exemplary” indicates the description is used as an example, rather than implying that it is an ideal. Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only. The scope of the invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

1. A method of fabricating a thin-film transistor, the method comprising:

providing a substrate;

forming an active layer over a surface of the substrate;

forming a dielectric layer on the active layer;

patterning the dielectric layer using a first mask, including exposing regions of the active layer, the patterned dielectric layer comprising a continuous patterned dielectric segment, the dielectric segment comprising a first patterned dielectric portion and a second patterned dielectric portion, the first patterned dielectric portion defining a thin-film transistor region on the active layer and the second patterned dielectric portion defining a gate pad region thereon;

forming a conductive layer on the exposed regions of the active layer, on the first patterned dielectric portion, and on the second patterned dielectric portion;

patterning the conductive layer and the exposed regions of the active layer using a second mask, including exposing parts of the first patterned dielectric portion and removing some of the exposed regions of the active layer to expose the substrate, the patterned conductive layer comprising a first continuous patterned conductive portion on a first section of the active layer, a second continuous patterned conductive portion on a second section of the active layer, and a third continuous patterned conductive portion on both the first and the second patterned dielectric portions, the first, second, and third continuous patterned conductive portions spaced apart from each other and each overlapping a different part of the first patterned dielectric portion;

forming a passivation layer on the substrate, on the patterned conductive layer, and on the exposed parts of the first patterned dielectric portion; and

patterning the passivation layer using a third mask, including forming windows through the passivation layer, a first one of the windows exposing a section of the first patterned conductive portion, a second one of the windows exposing a section of the second patterned conductive portion, and a third one of the windows exposing a section of the third patterned conductive portion.

2. The method of claim 1, further comprising forming a permanent barrier layer on the substrate prior to the step of forming the active layer over the substrate, and forming the active layer on the barrier layer.

3. The method of claim 1, wherein the first and second patterned conductive portions comprise source and drain terminals of the thin-film transistor, and the third patterned conductive portion comprises a gate terminal of the thin-film transistor.

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4. The method of claim 3, wherein the third patterned conductive portion further comprises the gate pad region of the TFT.

5. The method of claim 4, wherein the gate pad region of the TFT is exposed through the third window.

6. The method of claim 3, wherein the source and drain terminals of the thin-film transistor are each exposed through one of the first and second windows.

7. The method of claim 1, wherein the active layer is a continuous layer that extends between the substrate and the first patterned conductive portion, between the substrate and the second patterned conductive portion, and between the substrate and the continuous patterned dielectric segment.

8. The method of claim 1, wherein the step of patterning the conductive layer and the exposed regions of the active layer includes etching through the conductive layer and through the active layer such that an edge of the patterned conductive layer is aligned with an edge of the active layer along a plane perpendicular to the surface of the substrate.

9. The method of claim 1, wherein the first patterned dielectric portion comprises parallel edges on opposite sides of the first patterned dielectric portion, the first and second patterned conductive portions each overlaps only one of the parallel edges, and wherein the third patterned conductive portion extends across the first patterned dielectric portion between the first and second patterned conductive portions.

10. A method of fabricating part of readout circuitry for a plurality of photo-sensitive pixels in a digital radiographic detector, the readout circuitry comprising a thin-film transistor in each of the pixels, the method comprising:

providing a substrate;

forming an active layer on a surface of the substrate;

forming a dielectric layer on the active layer;

patterning the dielectric layer using a first mask, including removing portions of the dielectric layer and exposing regions of the active layer, the patterned dielectric layer comprising a continuous dielectric segment in each of the plurality of pixels and defining a thin-film transistor region on the active layer in each of the plurality of pixels;

forming a conductive layer on the patterned dielectric layer and on the exposed regions of the active layer;

patterning the conductive layer and the exposed regions of the active layer using a second mask to form three terminals in the conductive layer for each thin-film transistor, each of the three terminals in the conductive layer overlapping the continuous dielectric segment in each of the plurality of pixels, the step of patterning the conductive layer including removing portions of the conductive layer and the active layer down to the substrate;

forming a protective layer on portions of the substrate, on the patterned conductive layer, and on portions of the continuous dielectric segment in each of the plurality of pixels; and

patterning the protective layer using a third mask to expose a portion of each of the three terminals for each thin-film transistor through the protective layer.

11. The method of claim 10, wherein a first terminal and a second terminal of the three terminals are formed on the active layer, and wherein a third terminal of the three terminals is formed on the dielectric layer and is thereby insulated from the active layer.

12. The method of claim 11, wherein the third terminal comprises a gate region, an intermediate region, and a gate pad region, the gate region disposed on the dielectric layer between the first and second terminals.

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13. The method of claim **12**, wherein the gate pad region comprises the exposed portion of the third terminal, and wherein the gate region is not exposed through the protective layer.

14. The method of claim **13**, wherein the gate region and the gate pad region comprise portions of the third terminal that are wider than the intermediate region.

15. The method of claim **11**, wherein the first and second terminals comprise source and drain terminals for each thin-film transistor.

16. The method of claim **11**, further comprising removing portions of the conductive layer and the active layer down to the substrate such that at least one edge of the conductive layer is aligned with a corresponding edge of the active layer along a plane perpendicular to the surface of the substrate.

17. A digital radiographic detector comprising a plurality of pixel circuits, each of the pixel circuits comprising a thin-film transistor, and each of the thin-film transistors comprising:

- a substrate;
- an active layer on a portion the substrate;
- a continuous dielectric segment on a portion of the active layer;

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a first continuous conductive segment on a first portion of the active layer and on a first portion of the dielectric segment;

a second continuous conductive segment on a second portion of the active layer and on a second portion of the dielectric segment;

a third continuous conductive segment on a third portion of the dielectric segment and thereby insulated from the active layer; and

a continuous protective layer on the first, second, and third conductive segments, and on a fourth portion of the dielectric segment, the protective layer comprising an opening over each of the first, second, and third conductive segments to expose a pad portion thereof.

18. The detector of claim **17**, wherein the third continuous conductive segment is formed entirely on the dielectric segment.

19. The detector of claim **17**, wherein the active layer extends continuously between the substrate and the first continuous conductive segment, between the substrate and the second continuous conductive segment, and between the substrate and the continuous dielectric segment.

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